Systems Engineering Research Center

Expedited Systems Engineering for Rapid Capability and Urgent Needs

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Systems Engineering Research Center (SERC) Research Topic 34 (RT-34)
Expedited Systems Engineering for Rapid Capability and Urgent Needs

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INTRODUCTION

This Systems Engineering Research Center (SERC) research topic 34 (RT-34) examines expedited systems engineering (SE) as applied to rapid capability and urgent needs as developed in response to changing threats. The Defense Science Board (DSB) Task Force on the Fulfillment of Urgent Operational Needs (July 2009) identified more than 20 rapid-reaction programs and organizations addressing DoD urgent warfighter needs. Later, OSD/DDR&E conducted a study called "Rapid Capability Fielding Toolbox" released in March 2010. Recently GAO has examined how well the DoD handles rapid solutions to Joint Urgent Needs, and they have also specifically examined the acquisition activities for Special Ops urgent needs. These studies determined that the standard Department of Defense acquisition process is not designed to respond to the dynamic environment of rapid acquisition. These reports and others have also documented the problems and possible solutions surrounding rapid acquisition, rapid fielding and/or rapid prototyping. The recommendations have included acquisition process changes and introduction of new SE tools.

Lifecycle of urgent needs programs is driven by "time to market" as opposed to complete satisfaction of static requirements, with delivery expected in days/months versus years/decades. The processes and practices applied to urgent needs must add value and not require an excessive bureaucratic oversight to implement, while at the same time address, understand, and manage risk such that programs can understand better where to include, truncate, or eliminate systems engineering (SE) practices and processes. The original RT-34 hypothesis was that by defining, identifying, testing, and ultimately implementing expedited SE processes and practices, capability that results from urgent needs may be more effective, efficient, and longer lasting in the field. Potential second order effects are that expedited SE as applied to urgent needs could streamline specific future SE practices, as urgent becomes "normal," and findings could eventually improve SE processes for traditional programs as well. The intersection of these two extremes could become a "hybrid" approach to SE.

The RT-34 research team set out with the goal to identify the factors that contribute positively to rapid acquisition focusing on the systems engineering process. One can hypothesize that certain critical success factors from those organizations that do rapid acquisition may well be transferrable to traditional acquisition. These critical success factors may include aspects from their personnel/organization, the processes they use, or how they approach the product/system/solution.

This research effort studied over 30 organizations and individuals – from commercial, civil and DoD sectors – which have known experience in rapid development as shown in Table 1. These organizations and individuals were at the headquarters level and often represented a portfolio of rapid programs. The investigation attempted to identify any people, process or product related behaviors that the organizations thought most contributed to expedited systems engineering. The site visit discussions showed that expedited SE was conducted in the context of overall rapid development, and the responses from individuals focused more on the contributions of people to rapid development and acquisition success instead of a "secret sauce" of how to expedite SE.

It is also necessary to define what we mean by "rapid." Most define "rapid" as generally delivering a capability as quickly as 2 months and no longer than 24 months. However, we have also seen "rapid" referred to as "half the

time of traditional acquisition." The definition must also consider the context of the acquisition environment as well as the characteristics of the fielded capability, such as amount of operational capability/performance, warfighter satisfaction, safety of operations, manufacturability, and sustainability (repairs, parts, etc.). Many other design considerations may be critical, which must be balanced with time to market. We refer to "expedited systems engineering" as the set of systems engineering and engineering management activities used during a rapid acquisition, which may be tailored and scaled appropriately (or unfortunately eliminated or delayed inappropriately). This last approach has been termed technical debt.

The RT-34 team found an enthusiasm that is infectious throughout the organizations that regularly practice "rapid" successfully. This finding revealed that rapid organizations have a certain culture that fosters and enables a certain *esprit de corps*. We hope that exhilaration can spread throughout the entire acquisition community.

METHODOLOGY OVERVIEW

Research on success factors and factors categories is well documented for varied purposes in the Industrial Engineering community. Various types of success have been documented in project planning, control and monitoring, project management, organizations, external environment, process definition, and technical considerations. A recent research paper on "Critical Success Factors for Rapid, Innovative Solutions," (Lane et al) concluded that successful innovative organizations share certain characteristics regarding culture, risk, team size, solution patterns, engineering processes and innovation. These findings parallel Kelly Johnson's famous "14 Rules of Management" from the Lockheed Skunk Works program, where his motto was, "Be quick, be quiet, and be on time."

Based on these initial factors, literature review, inquiry and input from the SERC research council and the researchers' personal experience, a list of guiding questions was identified for unstructured site visits with subject matter experts (SME) at organizations known for conducting rapid development and/or rapid acquisition. It was assumed that such organizations also practiced, or would be familiar with, expedited systems engineering in the context of rapid development and fielding of systems. The questions, along with a short description of the research, were provided to each organization ahead of the visit.

After the first week of research, it was clear that the answers were naturally grouped into three categories as follows. A revised list of 37 questions was clustered accordingly and used for the remaining period of data collection:

1. <u>People</u> / organizational questions
2. <u>Process</u> questions regarding Systems Engineering and technical engineering management
3. <u>Product</u> questions regarding architectural aspects of the solution.

It should be noted that the questions were very engineering focused, to examine the systems engineering technical and technical management processes (e.g., risk, requirements, technical decision making, modeling, documentation, etc) as well as the product or solution architecture (e.g., interfaces, technical maturity, complexity, etc). The responses, however, nearly always pointed back to the people, who had a set of career experiences and a way of thinking that enabled them to make appropriate judgment calls on what systems engineering was needed, and that this process was enabled through the culture and leadership of the organization. The responses could be interpreted by the researchers, and the reader, to better describe system development or system acquisition, than strictly systems engineering.

The team targeted those organizations who have been acquiring Joint Urgent Operational Need Statement (JUONS) solutions or who had expertise in aspects of rapid non-traditional acquisition. Predominantly, the organizations were either Government defense acquisition offices or select defense industries. These

organizations are known for rapid, non-traditional acquisition. A short planning phase identified organizations practicing expedited systems engineering such as the Prototype Integration Facility at the U.S. Army Aviation and Missile Research Development and Engineering Center in Huntsville, AL, and the U.S. Special Operations Command (SOCOM) at McDill AFB, FL. The organizations were identified by those known to the SERC sponsors, the SERC Research Council, and the researchers; those identified in the DSB and GAO reports; and via referrals from other rapid organizations.

Initially our list included a variety of organizations from government and industry, as the original research plan called for us to analyze the start of the art in expedited SE within the DoD and commercial sector. As time went on, we narrowed the focus to government rapid acquisition offices, as these more closely represented the user community of interest to the sponsor and were more consistent with the future research intent to validate an expedited SE framework on a DoD acquisition program.

The notes from over 30 discussions with organizations and individuals were coded and tagged based on patterns of consistent responses.   The full list of site visits is shown in Table 1, which reflects 25 locations, some with discussions with multiple SMEs. The list is in chronological order, showing the increased focus on defense and Air Force organizations as the research progressed.

Table 1: List of Site Visits Conducted

1	The Aerospace Corporation Concept Design Center (CDC), Los Angeles, CA
2	American Institute of Aeronautics and Astronautics (AIAA) Space 2011 conference, Long Beach, CA (various discussions with SMEs from government, industry, and academia)
3	An aerospace industry innovation lab, Southern California
4	A rocket engine design company, Southern California
5	Annual SERC Research Review (ASRR), College Park, MD (various discussions and presentation notes, including a panel discussion on this research subject)
6	Small satellite development company
7	NASA Goddard Space Flight Center (GSFC), Greenbelt, MD (multiple separate discussions)
8	Operationally Responsive Space (ORS) Office, Kirtland AFB, NM (multiple discussions)
9	USAF Space Development and Test Directorate, Kirtland AFB, NM (multiple discussions)
10	Int'l Symposium for Personal & Commercial Spaceflight (ISPCS) (several discussions w/speakers & attendees)
11	International Women's Forum Annual Conference, Washington, DC (notes from panel presentation)
12	Air Force Rapid Capabilities Office (RCO), Washington DC
13	Intelligence Community, Washington DC (multiple organizations represented)
14	Georgia Tech Research Institute (GTRI) Collaborative Visualization Environment ("COVE"), Atlanta, GA
15	U.S. Army Prototype Integration Facility (PIF), Huntsville, AL
16	Aerospace / Engineering small business, Huntsville, AL (multiple discussions)
17	Big Safari - Program office and AF Program Executive Office, ISR-SOF, Wright-Patterson AFB OH
18	Air Force Research Lab (AFRL) Center for Rapid Product Development (CRPD), Wright-Patterson AFB, OH
19	AF Aeronautical Systems Center, Rapid Development Integration Facility (RDIF), Wright-Patterson AFB, OH
20	AFRL Air Vehicles Directorate, Wright-Patterson AFB, OH (multiple discussions)
21	Air Force Space Command / A5, Peterson AFB, CO
22	Air Force Space and Missile Systems Center, Rapid Reaction Branch, Colorado Springs, CO
23	Air Force Tactical Exploitation of National Capabilities (TENCAP), Schriever AFB, CO
24	Air Force Space and Missile Systems Center HQ, Los Angeles, CA
25	SOCOM Research and Development Acquisition Center (SORDAC), MacDill AFB, FL

In total, the 25 site visits represented:

- 15 government defense and intelligence community, of which 10 were Air Force
- 4 industry (all 4 conduct work for defense, civil, and commercial customers)
- 1 government civil space
- 1 Federally Funded Research and Development Center (FFRDC)
- 1 educational institution
- with the remaining 3 "site visits" conducted at conferences incorporating multiple individuals from all of these sectors.

The method used in this research is based on grounded theory. Grounded theory is a type of qualitative research methodology that allows theories to emerge from collected data. This collection of data comes from notes during discussions with the leadership of the "rapid" organizations—essentially experts in the field—to discern what made them successful and discover what drove their processes.   The research follows a systematic, yet flexible process to collect data, code and analyze the data, make connections, and see what theories can be generated. This "open coding" of labels is an important part of the analysis concerned with identifying, naming or labelling, categorizing, and describing phenomena found in the discussion notes. In this case, the theory is a set of principles for successful DoD rapid development, with a focus on systems engineering.

SUMMARY OF FINDINGS

It was clear from the site visits that expedited systems engineering is conducted in a context of rapid development and acquisition. When SMEs talk about what their organizations do, they focus on the bigger context, even though our questions focused on systems engineering. The responses showed that rapid development requires an integrated approach: *People* making judgments, *Processes* for task reductions, and *Product* aspects focused on rapid objectives. The "3 P's" of "people, process, and product" show organizations mindful of their people (with desired expertise, trust, motivation and expectations), the requirements, and the use of iteration to field solutions quickly and refine those requirements. Rapid organizations also seek out flexibility in process, contracting and right-sizing the solution to avoid undue oversight.   Further analysis reflects findings pertaining to efficient information/knowledge sharing, generally, but not exclusively achieved by small team collocation.   These organization were mindful of risk, but not to its complete removal from a program (if ever possible).   Rapid projects demonstrated both an exploitation of mature technologies and rapid solutions during their planning function, as well as the efficient and effective ability to execute those plans.

Like the different DoD Acquisition Category (ACAT) levels defined by RDT&E and Production dollar amounts, four different lanes of acquisition were identified that represent the different types of solutions selected by these rapid organizations. These four lanes consisted of: laboratory or operational prototyping, platform engineering and modification, integrated solutions and traditional weapon system acquisition. Huge flexibility exists within and throughout these lanes.

While we expected to find explanations for rapid SE processes practiced by rapid organizations, the number one finding was the strong role <u>people</u> play in a rapid context and an overwhelming view on the importance of "designing the design team." This is reflected in the culture and organizational ethos of rapid organizations. People create and implement the process to make the product.   We also observed that the rapid acquisition workforce is exposed to "hands-on" full lifecycle decision-making and their consequences. These experiences were often cited as critical rationale for someone being selected (or self-selecting) for a rapid project or career. These experiences are in contrast to what is experienced in a traditional full DoD5000 acquisition cycle. For example, in the 18 months it might take to field a rapid program, a traditional acquisition would see a portion

of one milestone. The compressed nature of rapid acquisition means that people have a greater appreciation for the end objective of the product – i.e., to quickly deliver the end effect required by the warfighter in the field. While these observations may not seem new, they provide the foundation for a broader framework of rapid development.

It must be pointed out that the site visit discussions generally took place at headquarters level and did not focus on particular projects or programs. The observations captured may be a result of bias in talking to higher management (across programs) rather than lower-level management, or engineering, within a small rapid project.

An original goal of the RT-34 research was to develop a framework for scaling SE activities in response to different development constraints, such as reduced development time, with intent to prepare a plan to validate the framework on a DoD acquisition program. As the research evolved, we discovered that in order to tailor or scale SE process, the right people with the right perspective and experiences needed to be in place, in the environment that enabled them to be successful. We identified several ways to validate the framework as well as future research questions that could be explored in the meantime.

Based on observation, interviews, and literature, a series of observations, or principles, begins to emerge that reflects a framework of rapid development. While we originally proposed a stacked model with increasing rigor, we finally elected to not infer any precedence, hierarchy, or increasing systems engineering rigor. For presentation in this report, we break our findings into three groups:

- Group 1: Direct Responses,
- Group 2: Direct Observations, and
- Group 3: Inferred Organizational Characteristics.

The Direct Responses in Group 1 provide an efficient affinity across all answers to our 37 questions. This set represents the top 11 "Organizational Best Practices". We observed strong evidence across the site visits for all 11 observations. In the process of validating the responses with the SMEs, reviewing against literature, and socializing the observations with others in the rapid and traditional community, we realized that the 11 observations are "not new" and also do not appear to be unique to rapid programs. We characterize these as practices that can be found in both rapid and traditional development programs.

Group 2 "Flexible Acquisition Practices" reflects Direct Observations that emerged from the site visits, but were not direct responses to the prepared questions. This group collects observations based on flexibility in acquisition practices, whether it be contract type, finance type, program management approach, documentation required, level of insight/oversight, etc. These practices are seen as critical for a rapid business environment. We originally did not seek out different types of rapid categories, or strictly acquisition management (such as contracting) findings; in fact, a ground rule of the research was that we would not seek to change the existing DoD5000 process. However, these observations about the acquisition environment emerged from the site visits and could not be ignored.

Group 3, the set of "Inferred Organizational Characteristics," represents aspects of a "Go Fast" Culture seen in the rapid organizations. This is where rapid organizations start to differ from traditional ones, and there is a shift in energy, commitment, and knowledge. These findings are motivated by an analysis of effective enterprise culture and business agility literature. The Group 3 characteristics include:

- Rapid organizations use intense and efficient knowledge-sharing to enable stabilization and synchronization of information
- Rapid organizations are characterized by a risk-tolerant culture
- Rapid organizations are structured for ambidexterity with a balance between exploration and exploitation
- Rapid development organizations exercise Real-time Management, with both empowerment at the lowest level at which sufficient knowledge and experience exists to make appropriate decisions as well as rapid access to top-level leadership to facilitate decision velocity.

Real-time management represents an integrative characteristic; it requires intense knowledge sharing, risk-focused culture (people knowing what risks to take and when and how), and the organizational ambidexterity that comes from a balance of exploration and exploitation.

The resulting RT-34 Expedited SE Framework is captured in Figure 1.
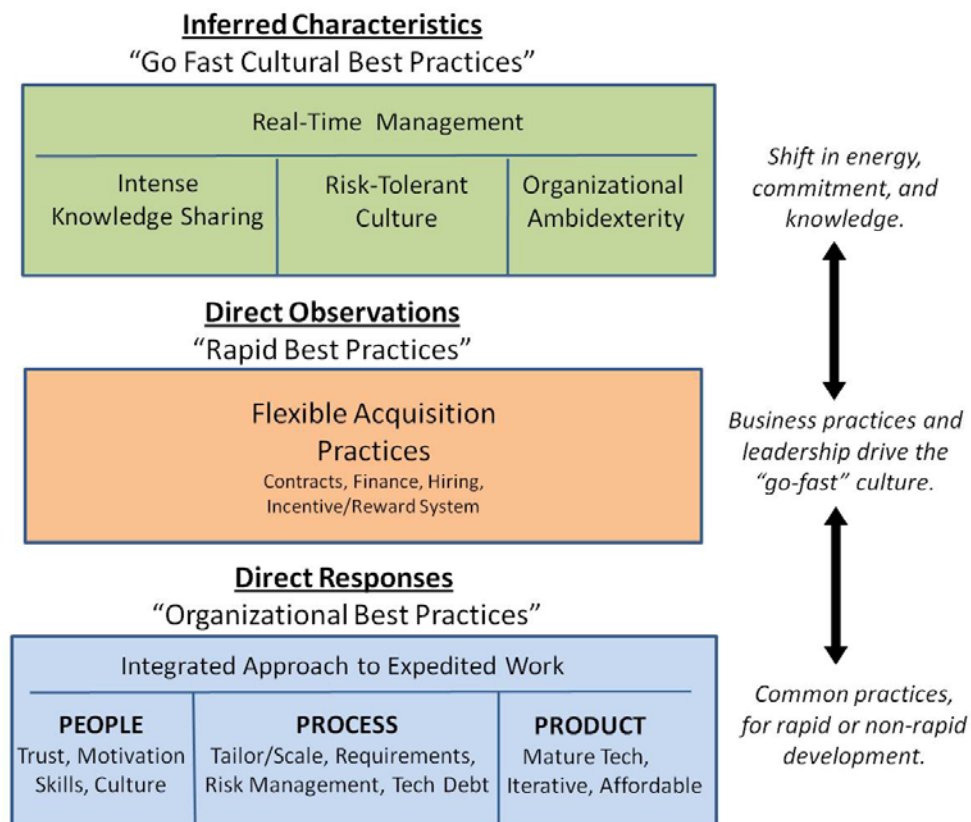
Figure 1: RT-34 Expedited SE Framework

This report goes into more detail about specific findings and recommendations associated with each level and several potential follow-on research thrusts. Two main research questions emerged that resonate with the sponsors:

1. What are the principles and attributes that are seen in each level of framework and do they apply equally across all domains and all lanes of acquisition?
2. How can human capital development improve by embedding acquisition personnel in programs to develop these principles and attributes?

Other questions arose after a peer-review "deep dive" of the RT-34 project. These questions included:

1. Is there a depiction of the framework that is hierarchical in nature, such that it infers, and justifies, precedence or causality?
2. How is DoD rapid acquisition different from DoD non-rapid or non-DoD rapid acquisition?
3. How can a traditional acquisition (large ACAT 1) embrace appropriate factors of rapid organizations, effectively becoming a "hybrid" program?

The answers to these questions will be referred to any follow-on research.

TABLE OF CONTENTS

FIGURES AND TABLES

1 INTRODUCTION

1.1 MOTIVATION

This SERC Research Task 34 (RT-34) set out to examine expedited systems engineering (SE) as applied to rapid capability and urgent needs as developed in response to changing threats. The lifecycle of urgent needs programs is driven by "time to market" as opposed to complete satisfaction of static requirements, with delivery expected in days/months versus years/decades. The processes and practices applied to urgent needs programs must add value and not require an excessive bureaucratic oversight to implement, while at the same time address, understand, and manage risk such that program management can understand better where to include, truncate, or eliminate systems engineering practices and processes. The original hypothesis was that by defining, identifying, testing, and ultimately implementing expedited SE processes and practices, capability that results from urgent needs may be more effective, efficient, and longer lasting in the field. Potential second order effects are that expedited SE as applied to urgent needs programs could streamline specific future SE practices, as urgent becomes "normal," and findings could eventually improve SE processes for traditional programs as well. The research evolved, through data collected at site visits with subject matter experts (SMEs), to examining the importance of the overall context of rapid development, i.e., the environment in which expedited SE is conducted.

This research is timely as the 2011 Defense Authorization Act called for the establishment of a "joint urgent operational need response fund" as part of its 2012 budget request. Further, the Air Force announced that it would manage its Next Generation Bomber under the auspices of the Rapid Capabilities Office because it offers more streamlined acquisition than other channels. RT-34 was proposed to focus on leveraging currently available methods, processes and tools to create a coherent expedited SE strategy that can be validated in practice.

Typical DoD systems experience change on many different time scales. To remain effective, these systems must accommodate change on each of these scales. As was noted in the SERC Systems 2020 report (Boehm et al., 2010), systems engineering capabilities need to be developed that achieve dramatic reduction in time to: develop a fieldable first-article product, implement foreseeable classes of fielded systems changes, and rapidly adapt to unforeseeable threats. Existing systems engineering tools, processes, and technologies poorly support rapid design changes or capability enhancements within acceptable cost and schedule constraints. Perhaps an artifact of the DoD acquisition process, rapid development has achieved point solutions, which make adaptation cumbersome and impractical in theatre. To increase development efficiency and ensure flexible solutions in the field, systems engineers need powerful, agile, interoperable, and scalable processes, tools and techniques. One of the DoD's goals is to embrace commercial marketplace approaches so that warfighters can have innovative solutions that are transitioned into capabilities in months, not years.

This research also has roots in the "Rapid Capability Fielding Toolbox" 60-day study conducted by DDR&E and released in March 2010. This study noted that the standard Department of Defense acquisition process is not designed to respond to the dynamic environment of rapid needs, and called for further investigations into concept engineering, capability engineering, and cultural change. Many DoD rapid development cells were identified, and a number of interviews with individuals working on rapid development projects were conducted.

Several Defense reports have documented in-depth studies on the problems and possible solutions surrounding rapid acquisition, rapid fielding and/or rapid prototyping. (Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2011) (Office of Secretary of Defense, Deputy Director for Research & Engineering, March 2010) (Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2009). Recommendations include acquisition process changes and introduction of new SE tools designed to handle a rapidly changing environment that challenges the current acquisition community.

First, most define "rapid" as generally delivering a capability as quickly as 2 months and no longer than 24 months (DSB, 2009). However we have also seen "rapid" referred to as "half the time of traditional acquisition". It will be important to further define "expedited" in relation to more traditional or deliberate acquisitions. More importantly, the characteristics of the fielded capability must be incorporated in the definition, such as amount of operational capability/performance, warfighter satisfaction, safety of operations, manufacturability, and sustainability (repairs, parts, etc). This report assumes "rapid" or "expedited" is less than 2 years.

1.2 PROBLEM STATEMENT

The Defense Science Board (DSB) Task Force on the Fulfillment of Urgent Operational Needs (July 2009) identified more than 20 rapid-reaction programs and organizations addressing DoD urgent warfighter needs. A subsequent DSB study found that urgent needs programs spent more than $50 billion between 2005-2009, and that urgent needs should be considered a critical, ongoing DoD institutional capability. In other words, "urgent" is becoming the new "normal." In March 2011, the GAO report, "DoD's Urgent Needs Processes Need a More Comprehensive Approach and Evaluation for Potential Consolidation," found that DoD has taken steps to improve fulfillment of urgent needs, but requires a common approach for addressing urgent needs.   This recent 2011 GAO report documents at least 31 entities that manage urgent needs and expedite the solutions to address them.   Thus, the problem is a lack of a framework that captures best practices for expedited SE across these rapid acquisition organizations, and this research proposes a framework for potential application across traditional acquisition.

1.3 DESCRIPTION OF THE RESEARCH, SERC RT-34

This SERC project on Expedited Systems Engineering examined the systems engineering and engineering management practices as applied to rapid capability and urgent needs as developed in response to changing threats. The successful techniques seen in rapid development and prototyping must scale to larger, more complex, supportable, and sustainable weapon systems. The systems engineering processes and practices applied to urgent needs should provide for innovative conceptual solutions, quickly prune the design space, and identify appropriate designs that can deliver warfighting capability expeditiously.

The purpose of the research was to explore and develop a scalable expedited SE framework for hybrid programs, i.e., those exploiting rapid development, but with the intent to have traditional lifecycle considerations for deployment, maintainability, reliability, adaptability and sustainment. Likewise, this new SE framework would be applicable to more traditional acquisition programs with a desire to incorporate scaled rapid development best practices. The focus is on systems engineering, not acquisition processes.   In other words, the framework should be easily tailorable or scalable to optimize for the circumstances of the program in question.

RT-34 research began September 1, 2011, with the predominance of the data collection and analysis completed by September 30, 2012, with time designated until December 30, 2012, to review the findings and confirm the next phase of research. The original program plan consisted of the following phases:

- Phase 1: Short planning phase to identify organizations practicing expedited systems engineering, including visiting selected organizations and incorporating input from the SERC Research Council.
- Phase 2: Analyze current state of the art in expedited systems engineering within DoD as well as non-DOD and commercial sector, and developing a framework for scaling SE activities in response to different development constraints, such as reduced development time.
- Phase 3: Prepare a plan for both validating the framework on a DoD acquisition program, or plan for follow-on research.
- Phase 4 (Future, Separate Funding): Execute the plan from Phase 3, with research to analyze the framework in action and iterate it based on observations and results as applied to a real program.

As will be described in this report, the research evolved to consider the broader context of the people, processes, and products involved in rapid development. We discovered that the framework was not mature enough to validate on a DoD acquisition program. Additional research questions arose that, once addressed, could enable the validation as originally intended.

1.4 METHODOLOGY

A recent research paper (Lane, Boehm, Bolas, Madni, & Turner, 2010) on "Critical Success Factors for Rapid, Innovative Solutions," posed a series of questions on potential program success factors. That paper concluded that successful innovative organizations share certain characteristics:

- Driven by business value
- Take calculated risks
- Proactive management and small agile teams
- Look for solution patterns that can be re-used
- Follow concurrent engineering practices
- Provide culture and environment that supports innovation.

Research on success factors and factors categories is well documented for varied purposes in the Industrial Engineering community. Various types of success factors (Van Scoter & Doolen, 2011) have been documented in project planning, control, monitoring, building, project, management, organization/people, external environment, process, and technical considerations.

Based on initial literature review, questions and input from the SERC Research Council and personal experience, a list of guiding questions was identified for unstructured interviews with subject matter experts (SMEs) working at headquarter level rapid development organizations. After the first week of research, it was obvious that the lines of inquiry could be clustered into 3 categories of people, process, and product. As a result, there was some refinement to these 37 questions and re-grouping into aspects of the people/ organization, the systems engineering and engineering management processes and the solution/ product. The re-grouped questions were used for the remaining discussions.

For example, some questions were:

- "How do you select/ design the team"? (people)
- "What is the formality of engineering documentation?" (process)
- "How do you translate prototypes to operational use?" (product)

The team targeted those organizations who have been acquiring Joint Urgent Operational Need Statement (JUONS) solutions or who had expertise in aspects of rapid non-traditional acquisition. Predominantly, the organizations were either Government defense acquisition offices or select defense industries. The organizations were identified by those known to the SERC sponsors, the SERC Research Council, and the researchers; those identified in the DSB and GAO reports; and via referrals from other rapid organizations.

Initially our list included a variety of organizations from government and industry, as the original research plan called for us to analyze the start of the art in expedited SE within the DoD and commercial sector. As time went on, we narrowed the focus to government rapid acquisition offices, as these more closely represented the user community of interest to the sponsor and were more consistent with the future research intent to validate an expedited SE framework on a DoD acquisition program.

Some of these included:

- Air Force Rapid Capabilities Office (RCO)
- U.S. Army Prototype Integration Facility (PIF)
- An aerospace industry innovation lab
- A small satellite development company
- NASA Goddard Space Flight Center
- Big Safari (Program office and USAF Program Executive Office, ISR-SOF)
- Air Force Research Lab (AFRL) Center for Rapid Product Development
- SOCOM Research and Development Acquisition Center (SORDAC).

The interview notes were coded and tagged based on patterns of consistent responses. Using the interview notes, an iterative qualitative analysis was performed using ATLAS.ti™ software in an effort to further explore the data for hidden connections and emergent trends. Transcribed notes from organizations were assigned to an ATLAS.ti™ hermeneutic unit. Using the observations derived through the interview process as codes, each document was coded appropriately against key words and phrases. The codes were organized into families of Product, Process, and People, which matched the clusters observed from the discussions. Originally 20 observations were first identified, aggregated down to 11. This "open coding" of labels is an important part of the analysis concerned with identifying, naming or labelling, categorizing, and describing phenomena found in the discussion notes. In this case, the theory is a set of principles for successful DoD rapid development, with a focus on systems engineering.

This technique is used in many inductive qualitative approaches, such as grounded theory. Grounded theory is a type of qualitative research methodology that allows theories to emerge from collected data. This collection of data comes from the notes during discussions with the leadership of the "rapid" organizations—essentially experts in the field—to discern what made them successful and discover what drove their processes.   The research follows a systematic, yet flexible process to collect data, code and analyze the data, make connections, and see what theories can be generated.

Based on observation, interviews, and literature, a series of observations, or principles, begins to emerge that reflects a framework of rapid development.   While we originally proposed a stacked model with increasing rigor, we finally elected to not infer any precedence, hierarchy, or increasing systems engineering rigor. For presentation in this report, we break our findings into three groups:

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The Direct Responses in Group 1 provide an efficient affinity across all answers to our 37 questions. This set represents the top 11 principles that emerged from the ATLAS.ti analysis, and are called "Organizational Best Practices". We observed strong evidence across the site visits for all 11 observations. In the process of validating the responses with the SMEs, reviewing against literature, and socializing the observations with others in the rapid and traditional community, we realized that the 11 observations are "not new" and do not appear to be unique to rapid programs. We characterize these as practices that can be found in both rapid and traditional development programs.

Group 2 "Flexible Acquisition Practices" reflects Direct Observations that emerged from the site visits, but were not direct responses to the prepared questions. This group collects observations based on flexibility in acquisition practices, whether it be contract type, finance type, program management approach, documentation required,

level of insight/oversight, etc. These practices are seen as critical for a rapid business environment. We originally did not seek out different types of rapid categories, or strictly acquisition management (such as contracting) findings; in fact, a ground rule of the research was that we would not seek to change the existing DoD5000 process. However, these observations about the acquisition environment emerged from the site visits and could not be ignored.

Group 3, the set of "Inferred Organizational Characteristics," represents aspects of a "Go Fast" Culture seen in the rapid organizations. This is where rapid organizations start to differ from traditional ones, and there is a shift in energy, commitment, and knowledge. These findings are motivated by an analysis of effective enterprise culture and business agility literature.

The research methodology, sites visited, and list of questions used for the site visits are provided in Appendix A.

1.5 FINDINGS AND ANALYSIS

The Direct Responses, Direct Observations, and Inferred Characteristics, along with a parsimonious set of Recommendations are summarized in Table 1-1. Some could claim these ideas are not new, and that these principles have been seen or demonstrated in some classified offices or a few select acquisition organizations throughout DoD.

There is an excitement and "vibe" to these organizations that cannot be captured from Table 1-1. These organizations appear to love what they are doing, probably because they feel closer to the need, the warfighter, and their ability to successfully deliver technological solutions.   Likewise, this excitement is contagious throughout the organizations and fosters leadership, a rapid culture, decision making skills, and lifecycle expertise.   Data analysis of the site visits (resulting in the Direct Responses) can be found in Appendix B.

1.6 EXPEDITED SE FRAMEWORK

Based on the site interviews, the coding/tagging of the interviews notes, extensive literature review, and the knowledge of the research team, the Expedited SE Framework began to develop. Three groups emerged.

- Group 1 - Direct Responses has direct correlation to interview responses of rapid organizations, and confirms best practices in project management and lean development systems.
- Group 2 - Direct Observations captures practices of rapid organizations that "live in a rapid world," that take an integrated approach to rapid development, by leveraging people, process and product appropriately, as well as seek out and monopolize flexible acquisition practices.
- Group 3 - Inferred Organizational Characteristics signifies a shift in energy, commitment and knowledge in rapid organizations, demonstrating the culture of effective organizations and those seen in the agility literature.

See Figure 1-1.

Table 1-1: Summary of RT-34 Observations, Findings, and Recommendations

Direct Responses	Recommendations
1. Use Mature Technology – Focus on the State of the Possible 2. Incremental Deployment (Development) is Part of the Product Plan 3. Strive for a Defined Set of Stable Requirements Focused on Warfighter Needs 4. Work to Exploit Maximum Flexibility Allowed 5. Designing out All Risk Takes Forever…Accept Some Risk 6. Keep an Eye on "Normalization" 7. Build and Maintain Trust 8. Populate Your Team with Specific Skills and Experience 9. Maintain High Levels of Motivation and Expectations 10. The Government Team Leads the Way 11. Right-size the Program - Eliminate or Reduce Major Program Oversight **Summary:** Rapid requires an integrated approach: People making judgments, Processes for task reductions, and Product aspects focused on rapid objectives.	Ensure that projects utilize prioritized organizational and project best practices Train program managers, engineers and contracting officers in organizational and cultural best practices, real-time management approaches, and the different flexibilities that exist. Encourage and enable programs to intensively share knowledge, have a risk-focused culture, and create an ambidextrous organizational structure Share knowledge, experience, mechanisms and lessons learned across programs and organizations Quantitatively monitor progress in expediting SE processes, and use the measurements to improve both schedule acceleration and the ability to estimate it
Direct Observations	Use DOD rapid organizations as a testbed to introduce digitally-enabled solutions
Not a single Rapid, but many different flexible Rapids with flexible lanes of acquisition and business practices.	
Inferred Characteristics	Develop the acquisition workforce using rapid programs to provide full lifecycle insight and hands-on experience.
• Intense and efficient knowledge-sharing is used to enable stabilization and synchronization of information • Rapid organizations are characterized by a risk-tolerant culture • Rapid organizations are structured for ambidexterity with a balance between exploration and exploitation. • Rapid Development organizations exercise Real-time Management.	

1.7 REPORT ORGANIZATION

The next three chapters (Chapter 2-4) detail each of three Groups from the Framework (Figure 1-1). Chapter 5 offers conclusion and some future research and application considerations. An epilogue to the research, based on a workshop at the 16th Annual Practical Software and Systems Measurement (PSM) User's Group Conference, is provided in Chapter 6.

Appendix A describes the methodology with the site visits conducted and questions asked of the SMEs. Appendix B captures the ATLAS.ti™data analysis. Relations to other SERC RTs is provided in Appendix C and details on some integrated tools with application to expedited SE can be found in Appendix D. Appendix E is a paper that describes an application of schedule-driven project estimation (using CORADMO).
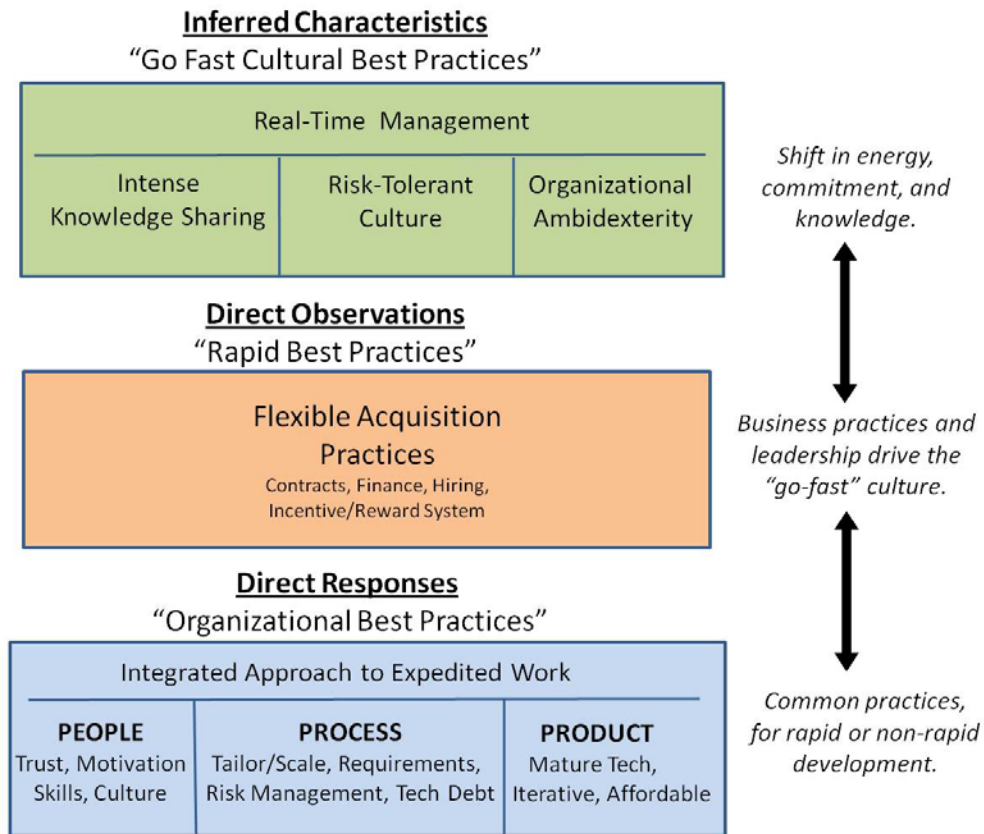
Figure 1-1: RT-34 Expedited SE Framework

2 DIRECT RESPONSES FOR ORGANIZATIONAL BEST PRACTICES (GROUP 1)

2.1 INTRODUCTION

This chapter introduces the core findings from the site visits and interviews, and places those in the context of expedited acquisition and work reduction techniques.   Some may read this chapter and see the core findings as "not new."   In the current program management and lean product development communities, indeed, many of these findings have been observed in the literature (Morgan & Liker, 2006; Oehmen, 2012). Similarly, for those who practice DoD acquisition in some niche areas (laboratory or operational prototyping, classified acquisition or platform modification shops), some of these findings may also be commonplace. Many organizations – traditional and rapid, are starting to use more of these practices. This chapter focuses on Group 1 of the framework.

2.2 OBSERVATIONS FROM SITE VISIT DISCUSSIONS

Appendix A describes the methodology for the selection of site visits and the questions posed to organizations and individuals conducting rapid development and practicing expedited systems engineering. Appendix B describes the data analysis conducted on the notes from these discussions.

The following practices are a set of consistent observations that have been coded from discussion notes from the site visits. Over 30 discussions were conducted from 25 site visits, including a number of informal discussions and panel presentations at conferences.

This section describes the "Group 1" direct responses from the site visit discussions as analyzed and derived from 22 full site visit discussions, which excludes inputs from conferences. Appendices A and B further describe the process. There are 11 direct responses.

In summary, one major finding emerged that reflects how all of the direct responses combine to create an integrated approach to rapid development. We did not see just one process, or one product, that resulted in expedited systems engineering. In fact, the responses were much broader about the context of the overall environment, the warfighter need, the acquisition practices, and the combination of people, processes and product coming together for success.

Summary Observation: **Rapid requires an integrated approach: People making judgments, Processes for task reductions, and Product aspects focused on rapid objectives.**

2.2.1 PRODUCT PRACTICES

Smart decisions on the system solution can greatly lower cost and expedite product delivery. But the mindset must be to reuse and repurpose, to the maximal extent possible, mature technology and legacy systems with an eye toward reduced complexity.

Observation 1: Use Mature Technology – Focus on the State of the Possible

- **Focus on integration of mature technologies**
- **Reuse existing capabilities, platforms, etc. – especially if they are flight-certified**
- **Reduce Complexity**

In rapid acquisition, untested and unproven technology poses an enormous risk to system success. Unlike most traditional acquisition programs, there is no time for technology to mature, in other words, no time for schedule slips due to immature technology struggling to develop. To avoid this pitfall, most rapid programs focus engineering efforts on the interfaces required to blend multiple existing technologies into a system capable of providing the desired set of capabilities. Another aspect of rapid is modifying an existing platform or simply adding subsystems and components. Program teams stay abreast of emerging technology and leverage the work done by industry and other military programs. They then engineer a system-of-systems solution to meet requirements. This bounds their design space within the state of the possible – that has, in part, already been proven. In Technology Readiness Level (TRL) terms, this means nothing less than a TRL 6, preferably 7 or 8. This, in combination with the concepts of reuse and incremental development, allow these teams to field quickly, but generationally provide more and more capability.

In many cases, the urgent need requests are to satisfy a newly emerged operational requirement. These organizations perform an abbreviated analysis of alternatives (AoA) to determine how best to meet that need. By the time the request arrives at one of these organizations, current technical capabilities indicate a materiel solution can be developed for the warfighter. Often the concept of delivering a partial solution is driven not only by time, but also by technical maturity. While a laboratory may have proven that something is feasibly possible, its integration into the operational battlefield typically is several years away until it matures. However, by working closely with the end user, the lab may be able to get new technology into the hands of the warfighter sooner as both a test bed and a way to meet operational needs. The lab can also leverage existing components and integrate them in a new or innovative way, these organizations are able to provide an equivalent or interim solution in short order. In this environment, the warfighter is given something to use now, and as technology matures, they can expect greater capability in the future that incorporates the experience collected in the field.

Another essential characteristic of rapid product development is the reuse of existing technical capabilities. This is further improved when existing technical capabilities are integrated onto existing platforms. A great example is a recent modification one organization performed to improve a small fleet of Combat Search and Rescue (CSAR) helicopters. Rather than develop a new forward looking infrared radar (FLIR) pod or lift hoist, the team examined the operational requirements requested by the user and identified existing technology currently being installed by the US Army on Department of State and Federal Bureau of Investigation helicopters. This reuse approach saved the program office over half of the potential contracted price (about $3M saved) and 12 months of schedule. In addition, the customer also received a Government-owned technical data package (TDP) because the design and engineering work was done in-house.   Another significant reduction in time for this example was the time saved in flight test by using equipment that had already been flight-certified. This approach created huge efficiencies in their flight test program as many test requirements had already been accomplished by a previous program.

However, this observation should be placed in context to the lanes of acquisition, discussed in Chapter 4. Laboratory prototypes tend to push technology as greatly improved ways to provide existing capability or provide new capabilities.   While we observed that schedule demands often resulted in technologically mature solutions, the use of immature or state-of-the-art technologies would be appropriate when no other concept exists, or time urgency can be relaxed or when the risk is worth it.   Essentially, choice of mature technology is another decision that can be approached through a balanced risk management process.

Observation 2: Incremental Deployment (Development) is Part of the Product Plan

- **"Generational development" - plan for technology maturity, advancement, and cycles**
- **Look for unpredicted outcomes**
- **Prototyping/Test infrastructure**

Part of the agreement of accepting a partial solution may also include the plan for incremental development. When this concept is decided upon from the beginning of any development program, it enables "generational development" – an intentional plan for technology maturity, advancement, and cycles of growth. This may be done by using open architectures, and modular concepts, clearly defining system interfaces, and utilizing industry standards. When planning for incremental growth in platform capabilities from the start, particular systems level planning is put into place. This approach allows known or unknown technical improvements to be more easily integrated into the baseline system—providing faster upgrading and an enhanced ability to share system level data. Overall, this approach will extend the system lifecycle and enhance its ability to flexibly meet the needs of an ever-changing technical and operational environment.

As rapid organizations march through their development programs, many are constantly looking for unpredicted design outcomes. In one organization, during the latter stages of product development a specific set of questions was asked: Who else could use this? How else could it be used? What does this enable next? How could this be used against us? This series of questions put this team in the right mindset to further the development and utilization of their products and think of the application beyond the immediate urgent need and into a future program of record or other user requirement.

One observation, not included in the SME questions, was physically observed – the infrastructure to best support iterative development. During our visits, many organizations had the ability and facilities to accomplish rapid prototype and test. Iteration implies incremental test and feedback. This could be at contractor facilities, but was generally observed in government owned-government operated facilities. These rapid organizations had the ability to test, or had good working relations with test organizations or had their own test organizations. Thus, these organizations had the infrastructure to experiment on target hardware, prototype solutions, and incrementally develop, test, deliver and get feedback.

2.2.2 SYSTEM/PRODUCT SUMMARY

In retrospect, these two observations, the use of incremental development and the use of mature technology, attempt to reduce system complexity. While the concept of system complexity was not specifically mentioned during SME discussions, we consider this a semantically equivalent finding. Complexity can be measured by the type and number of components within a solution, the degree of interconnections of those components and the type and amount of coupling between the components.   Often by reusing components, the focus becomes on quickly integrating these components with standard connections.

Depending on the design, we saw the integration of new components with other new components and new components with old (legacy) components/ platforms.   Having well defined interfaces allows new components to be more easily integrated with other new components.   For example, USB interfaces allow microprocessors to be integrated easily with peripherals. In another example, Operationally Response Space (ORS) developed a plug-and-plug space vehicle bus for future fast and simple integration of different payloads.

Many assume that reuse of existing components will reduce risk and deployment time directly. Rather, a different risk is realized - the risk of using a component in a potentially different application, with an unknown requirements and development (and manufacturing) history. While urgent needs may require mature technologies and non-development items (NDI) or COTS, there may be a new set of issues for any rapid solution that may be enduring. An open issue that requires further research, proposed in Chapter 5, is the balance between long term sustainability, affordability, and flexibility for future iterations.

Standard interfaces, both internal and external, still present challenges to rapid solutions and interoperability. Interoperability has been highlighted as a problem within the Department of Defense (DoD) since 1965 (Ford et al, 2007). One of the most used definitions for interoperability, from an outdated Joint Publication, is the ability of

systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together" (Ford, 2008). Some standards facilitate interoperability; others are challenged by consistent interpretation. One related concept is that of a "Convergence Protocol" (USAF Scientific Advisory Board, 2005).   These are those standards that are catalysts for widespread connectivity and capability enhancements; one such convergence protocol is the worldwide impact of TCP/IP.

Bottom line, the approach was to keep the system solution as simple as possible, trading out items that are not critical to success, and making maximum use of mature technologies within an iterative development process.

2.2.3 PROCESS PRACTICES

By first focusing on validating requirements, rapid organizations then exploited and executed their programs with the greatest flexibility allowed.

Observation 3: Strive Toward a Defined Set of Tolerable Stable Requirements Focused on Warfighter Needs

- **Get the requirements right--everything you do stems from them**
- **Capability based requirements rooted in customer derived "CONOPS"**
- **Use solid systems engineering (SE)**
- **Expedite trade studies – then make a decision and press forward**
- **Focus on providing the "23-80%" solution**

Defining stable requirements focused on the customer needs was one of the most frequently occurring principles during the SME discussions. Not only is there not enough time to do everything a customer is asking for, but customers often ask for more than they really need to meet their operational objectives. It quickly became evident that every one of these organizations spends a significant amount of time up-front, face-to-face with their customer discussing requirements and operational context. They may actually spend more time hashing out a solid set of requirements than they do in actual design and production.

Our discussions brought to light several frustrations of the requirements development process.   Customer disconnects or unrealistic expectations may emerge because customers are unaware of the state-of-the-possible. Customers may not understand how difficult it might be to accomplish their requests. Occasionally, a customer may have observed a system used by another entity and think "I need one of those"—seeing a product versus identifying a specific capability.   In response, the rapid organizations are deeply rooted in a capability based approach to requirements analysis. This drives concepts of operations (CONOPS) based analysis, where the customer must clearly define specific needs, uses, or capabilities for the system—in an operational context.

Equally important is an effort to keep the requirements stable. Regardless of the scope of a project, requirements creep will negatively impact the timeline of a project, delaying the delivery of operational capabilities to the warfighter. Further, requirement changes potentially weaken the scope of the project or may negate any perceived increase in baseline capability. As a tenant for rapid SE, stabilizing requirements starts with ensuring the requirements are right—in other words, directly interacting with the customer to determine what the paramount needs are rather then satisfying all-inclusive wants. Organizations that consistently execute rapid SE and acquisitions are rooted in high-quality requirements. In essence, rapid development requires stable requirements.

Rapid organizations validate requirements early and often with the customer to determine needs based on capabilities with the ultimate goal to deliver an effect. The acquiring organization must be willing to push back against unfeasible requirements, or schedule impacting requirements, in the interest of time. As one senior

officer explained, "[The organization must] fight hard to have the warfighter make trades" to establish requirements that are possible in the desired timeframe. Simply put, focus on valid requirements that can be met by the state of the possible in a short amount of time.

The application of solid SE principles during early requirements definition promotes unambiguous and achievable requirements. SE ideologies emphasize relating requirements to specific design criteria and ensuring the traceability of those requirements from the system-level downward. Through an interactive process with the customer, the focus evolves to one of concept refinement, defining the system trade-space, developing system-level and derived requirements, making appropriate system-level tradeoff decisions and critically searching for problems and disconnects. Applying these concepts at the beginning of the project (and iteratively throughout) can foster achievable objectives with reduced late-in-phase design effort.

Iterative development, as found in Observation 2.2, strongly relates to this observation as well.   Some engineers will challenge this, saying that all requirements, especially for large acquisitions, can be defined and stabilized. This may be true. Complexity of the technologies, system interdependencies, along with tactics, techniques and procedures of the people using the systems, and a dynamic threat environment may limit the ability to stabilize requirements early.   Often the discovery of what are the real "100%" of the requirements will change, especially if a smaller set of requirements is first deployed. For the most complex systems, customers often don't know precisely in advance what they actually need, but instead must iterate through a series of experiments to sort out both operational utility and effectiveness of a final solution.

The short duration of rapid development projects naturally lends to more stability in requirements. Grand changes in technical maturity or capability are not often experienced in the short lifecycle of the project. There are also fewer changes in political administration (funding), leadership (rotating Colonels) and program personnel; each personality brings to the project a new perspective or priority than their predecessor. And, requirements stemming directly from urgent warfighter needs are less likely to change over a short period of time.

Ironically, requirements creep can become a pitfall of regular customer involvement in requirements refinement. Several organizations emphasized the necessity to fight requirements creep once stable requirements have been established. However, stopping creep cannot be done at the expense of customer and user involvement. In this manner, an art must be developed to keep the user in the loop without allowing for spurious changes to the project once underway. A chief task for the Systems Engineer should be persistent analysis of derived requirements in conjunction with making difficult decisions regarding system requirement trades and concept refinement. Part of this process is understanding the real need behind the warfighter's request.

Rapid programs rarely provide the customer with 100% of what they ask for. SMEs expressed the typical "80% solution" concept, but also a more realistic (albeit academic in number) "23% solution" in practice. By framing the question to the customer as "Instead of XX in 10 years, I can give you XY in a few," the user may be more inclined to agree. One expert with a space-focused organization commented, "50% or 23% done quickly can be very acceptable." Often eliminating or modifying certain requirements will provide the warfighter with a viable solution to a problem within an expedited, achievable timeline rather than a never-ending pursuit of the 100% solution.

The requirements process often boils down to the program team getting the customer to clearly articulate exactly what capabilities they need in the field. Just as critically, these conversations and research by the development team help the customer understand the performance and schedule risk of pushing the state-of-the art too far. Clearly understanding the capabilities of industry and current technology significantly improves customer expectations of what can be accomplished in a short amount of time. This then shapes the product design space. Then, after some quick analysis, the program team can say, "A 100% solution will take 4 years. However, I can get 40% of what you want in about 9 months and it will do X, Y and Z. Will that work?" The answer is often an

enthusiastic "yes". In this environment, an organization can be seen as heroic for being able to provide a solution that does two or three things really well, delivered in a short amount of time; rather than providing the warfighter a system that can do those same three things and assumedly several others after five years (or more).

The researchers also met with two well-known and published examples of organizations that practice the importance of up front concept design and requirements: the Aerospace Corporation Concept Design Center (CDC) and the Georgia Tech Research Institute (GTRI) Collaborative Visualization Environment ("COVE"). Both facilities create and evaluate conceptual designs in a synergistic, concurrent, collaborative manner with a collocated team of design engineers and customers applied to a specific domain. The environment allows rapid and simultaneous requirements development and design engineering with real-time tradeoffs and "what if" analyses.

This requires quite a bit of pre-work with the users to first describe the purpose of the exercise (rapid agreement on requirements) and second to narrow down the questions to be addressed in the exercise. As an example, the CDC specializes in spacecraft

Decision Making Tools at the GTRI Collaborative Visualization Environment	
• Collaboration and voting • Modeling and Simulation • Leadership Empowerment • Technology Readiness Levels	• SYSML • Diamond Model • Decision Metrics (quantify cost of possible delays

design and has brought Air Force program offices into the CDC to narrow down spacecraft requirements for development of a Request for Proposal (RFP). As more and more users become familiar with the CDC, the Air Force customer has used the facility in increasing ways both for concept development as well as for trade studies in later lifecycle phases. The GTRI facility is very similar for other domains. Both are capable of classified projects.

**Figure 2-2: Aerospace Corporation Concept Design Center (CDC) [*LEFT*]
& Georgia Tech Research Institute (GTRI) Collaborative Visualization Environment ("COVE") [*RIGHT*]**

Observation 4: Work to Exploit Maximum Flexibility Allowed

- **Tailor the acquisition and system engineering process to the product**
- **Establish a clear and short approval chain**
- **Document what is important and decisions made – not much else**
- **Use various contracting vehicles to accomplish different tasks**

It may appear to the casual viewer that rapid organizations are the "Wild West" of the DoD acquisition community. However, solid acquisition and engineering approaches to solving complex technical problems and fulfilling real operational needs were consistently observed. Because of the specialized nature of each office,

many have developed in-house processes adaptable to each new program. This ensures each program office has a specific roadmap leading it to success, and each project lives within its own specific process and lifespan.

In the interest of time, these organizations ensure every acquisition or SE process they implement is tailored to the end product or the desired effect to be delivered. Anything not required, deemed unnecessary, or found to be non-value added is set aside. Adhering to the intent of DoDI 5000.02, they apply it to their specific product without excess. To the untrained eye it may appear these organizations are skipping steps in the acquisition process. The research indicates these steps are not skipped, but rather tailored to meet the stringent timelines required to deliver product to the warfighter. For example, a Systems Engineering Plan (SEP) may consist of only two pages within a higher level document, instead of a 30 page stand-alone file. They use formal and informal review processes, specifically performance-based and milestone-type reviews, with just the right people in attendance to make go/no-go decisions on the spot. The focus is to document important technical and programmatic information and critical decisions. There are no documents produced for documentation sake.

In discussion with some organizations, it became evident their approval chain for reviews and program milestone approval had been shortened. Additionally, the approval chains were clearly defined. In most of these organizations, there are very few extraneous persons in the review chain that do not have some sort of approval authority or intrinsic value added (such as legal or contracting).

The brevity of these approval chains often stems from a Program Management Directive (PMD) outlining the decision making authority within these organizations. This document can outline specific positions with approval authority, typically pushing it down to a lower level of responsibility within the organization, shortening the approval chain and reducing the time required to make programmatic decisions. Some of this brevity may also stem from the classification level of the project, literally preventing some personnel from participating. Finally, program size may keep budgets under Major Defense Acquisition Program (MDAP) thresholds.

An often frustrating part of the acquisition process is bureaucracy. SMEs indicated that occasionally some individuals believe they need to be part of a review process ostensibly because of their position, leadership or not, which can become a road block for the program team. Conversations reveal this behavior may be caused by personal agendas, need for a feeling of empowerment or importance, or simply because the process has always been done a certain way. In rapid programs, if someone does not have value to add, they are not included. This was not to the exclusion of participation, but value added by personnel directly or indirectly involved in the process is critically analyzed. This analysis helps avoid the pitfall of people merely adding time to the process and pushing back on the review process without bona fide authority to do so.

Another practice is to combine, not skip, program level reviews. For example, test plans, Technical Readiness Review Boards (TRRB), Safety Review Boards – if deemed low risk, can be signed off at the local level in a single review. This is also applied to pre-milestone decision reviews as well. This concept does not indicate system engineering processes and thoroughness are brushed aside. The approach is to shorten the approval and review process timeline by combining review processes and reducing the lull created by waiting for a review process to take place – not to diminish the quality of the product or eliminate SE analysis processes.

Another common trend is the use of various innovative contracting vehicles to accomplish different tasks, some of which are in place for several years, for use when needed or to provide frequently used specific services. For example, Indefinite Delivery Indefinite Quantity (IDIQ) contracts were important to several organizations to provide as-needed support on a reoccurring basis. This approach requires a special type of contracting capability, referred to by one organization as "creative contracting". This can only be done by contracting officers who are knowledgeable about and willing to investigate the art of contracting – discover how something could be put on contract in a way most advantageous to the product and program situation—all within the bounds and utilizing the full flexibility of the existing Federal Acquisition Regulation (FAR) and policy.

Observation 5: Designing out All Risk Takes Forever – Accept Some Risk

- **Creative (and implementable) solutions are allowed**
- **Mitigate risk through the use of mature and proven technology**
- **Potential for failure is accepted, because providing something may be better than nothing**
- **Determine the level of risk the customer is willing to accept**

The rapid organizations we met with operate under an uncommon risk paradigm when compared to many large DoD acquisition programs. In rapid, the potential for "failure" through providing only a partial or short term solution to the field may be acceptable, as this may be preferable to delivering nothing at all. Rapid teams are made up of technical experts who cognitively assess the risks of different technical solutions throughout the design process, sometimes with formal risk assessment processes in place. This idea of risk mitigation through use of mature and proven technology led several programs to adopt the concept of demonstrations or prototyping versus modeling as a better use of time and resources. The bottom line often came down to the level of program or technical risk the customer is willing to accept and the limited time available—emanating from detailed conversations with the customer. If the warfighter could utilize a partial solution and is willing to take some technical risks with a prototype in the field, delivery times are considerably shortened and feasible solutions can be arrived at allowing testing in the field and real-world feedback for incremental improvements.

According to Merriam-Webster's dictionary, "create" is defined as: To produce through imaginative skill (Merriam-Webster, 2012). While thinking creatively is not necessarily commonplace in everyday acquisition, in rapid acquisition it is absolutely acceptable and quite often critical to success. Creative and implementable solutions must be sought in order to do things rapidly. Some of this success hinges on expert understanding of the design space, potential technical solutions, and the ability to integrate existing technologies. Rapid programs work through a rigorous design process, working to identify, eliminate and accept risks. However, attempting to design-out all risk is a time consuming and costly process, and not realistic if attempting to get a solution out to the customer quickly.

Observation 6: Keep an Eye on "Normalization"

- **Track your technical debt**
- **Do configuration management, even if it is in your engineer's head**
- **Buy or maintain data rights or a build-to spec**

"Normalization" is a term heard at one of the larger DoD rapid acquisition offices, but the concept was reoccurring. It describes the transition of a program from a prototype or rapid project into a major (mainstream) acquisition program. Most of the organizations interviewed typically work in small-rate production runs (a few to less than 15). Thus, the investments required for product implementation are minimal compared with a large aircraft program predestined for a full rate production phase and years of sustainment. However, as many rapid projects have the potential to become normalized or productized, it is advantageous for these offices to keep their eyes on this possibility and be prepared for a full-scale transition. Effectively, this term relates to a program that was originally schedule-driven, but has been asked to become lifecycle-optimized and to transition (usually after the fact) to a program of record. This typically happens when an urgent need is determined to be an enduring requirement.

Technical debt, another term heard at one of the organizations, is a concept coined by Ward Cunningham in the early 1990s as a way to describe the risks and compromises made in rapid development. He first applied the concept to software development. "Shipping first time code is like going into debt. A little debt speeds development so long as it is paid back promptly with a rewrite... The danger occurs when the debt is not repaid. Every minute spent on not-quite-right code counts as interest on that debt. Entire engineering organizations can be brought to a stand-still under the debt load of an unconsolidated implementation, object-oriented or otherwise." (Cunningham, 1992)

Cunningham has recently commented that this concept has been misinterpreted and confused with the idea that you can do sloppy or poor work up front with the intention of doing a good job later. (Cunningham, 2009) That is not the case with the rapid organization whose primary purpose is to provide useful products to the warfighters in the field. Providing a poorly executed product to the field, however rapidly, would quickly render these organizations useless.

The technical debt concept allows these organizations to move forward quickly, before they may fully understand the problem, all the while tracking what processes has been potentially skipped or tailored (both purposeful tailoring or ad hoc tailoring). The importance of tracking these processes comes into play as the program matures, particularly if the program is successful and is transformed into a larger military procurement program or new program of record. It should be noted that tailoring may, or may not, incur technical debt. If these processes or analyses are not tracked, it will be difficult to know what work might need to be completed as the program moves into traditional maturity. For example, on a small-scale small-shop project, configuration management may have been done in the engineer's head. However, if there is a desire to mass produce an item, configuration management and a true product baseline will be needed. Knowing what systems-level work has or has not been accomplished is critical to successful transition to a normalized and potentially mass produced product. It is often difficult for rapid organizations to accomplish this transition because of the time it takes to overcome the technical debts, particularly in the documentation required for a program of record.

This concept also confirms a popular topic amongst all acquisition and engineering programs—data rights. Many of these organizations specifically mentioned the benefits of purchasing or maintaining some level of government owned data. The level of data required varies between programs, but the intent was consistent: Have enough data to provide the ability to modify when necessary, maintain competition, and facilitate a transition toward normalization.

2.2.4 PEOPLE PRACTICES

The discussions with SMEs uncovered aspects of trust, strong team skills, empowered leadership and a unique culture with high expectations of the team.

Observation 7: Build and Maintain Trust

- **Develop solid relationships and work to maintain them**
- **Empowered leadership**
- **Autonomy for Program Managers/Engineers**
- **Consistent customer input & buy-in every step of the way**

Building and maintaining trust enables empowered teams working together, being allowed to make decisions, leaders standing behind their decisions, and dealing with success or failures as they are encountered. This building process is a struggle at times and may even involve internal and external conflicts. These conflicts must be enriching experiences, opportunities to learn, grow, cooperate, and move forward. Agile development thrives in a culture "where people feel comfortable and empowered by having many degrees of freedom". The scope of trust is an important element for expeditious behavior and extends throughout the organizations in acquisition, development and deployment, and particularly in the interfaces between these three. As noted by P. Lencioni ("Five Dysfunctions of a Team") and others, Trust is the critical foundation of teamwork without which it is not possible to effectively team or collaborate. Trust becomes ever more important amongst the parties at higher levels of decision making.

Rapid organizations repeatedly showed leadership at all levels providing top cover to allow teams to focus on executing the mission. These same leaders must be empowered and trusted at the lowest level possible to make tactical and strategic decisions. When decision making authority is placed at a low level it shortens the process, reduces opportunity for stall time, and fosters close relationships.

Most discussions conducted circled back to strong relationships with the customer. From this perspective, it was vital to have the customer consistently involved in the decision making process and to gather their feedback as the process moved forward. This was accomplished in many different ways: Short- and/or long-term on site customer representatives, customer input and regular conversations through reviews, or simply a close relationship and coordination process. Regardless of how the customer was included on the team, it was clear that trust in the team's ability to deliver was vital to project success.

Trust is built through expertise, show of confidence, and record of performance. On the outside, it appears relationships exist on an organizational level. However, our discussions showed building and maintaining trust within a program team required constant nurturing. Further, trusting relationships showed just as important between individuals within these teams as building and maintaining trust with customers and senior leaders. It was consistently demonstrated that personal trust relationships at every level built foundations for organization reputation and credibility. In addition, the existence of a trust network appeared important for developing connections inside and outside the organizations. Further, personal trust networks became intertwined – enhancing and extending the capabilities and connections between individuals and organizations. These relationships were often sustained into future jobs. This helps quickly build trust by leveraging pre-existing and proven relationships to build new ones.

Individuals build trust with one another through demonstrated commitment and competence. A successful acquisition team must have highly skilled acquisition professionals. But it is only through the consistent application of those skills that trust is built with leadership and individual or organizational autonomy is granted. Thus, not only must the desire to grant autonomy or empowerment exist in the leader, it must be earned by those at the lower level. It is on the back of established trust relationships with senior leadership and the customer that this autonomy allows small teams to rapidly move programs forward.

Observation 8: Populate Your Team with Specific Skills and Experience

- **Hand pick your team…or grow your own**
- **Acquire people with the right education, experience, and personality**
- **Build the right team for each project**

The SME discussions alluded to hand picking teams and developing specific skill sets as a key aspect of success. Data indicated over 90% of the interviewed organizations handpicked their staff. Organizations identified required skills needed for each project and took necessary actions to acquire that skill set. Several methods of acquiring these skill sets were used: handpick new individuals, grow/groom current personnel (such as through mentoring, shadowing, or on-the-job experiences), hire contractor support, and reorganize teams. For rapid organizations, these vital individuals, either of their own accord or external grooming, become experts with very specific skill sets and a broad set of experiences. These individuals can then apply their skill sets to projects with specific customers, technologies or operational contexts.

Several senior leaders interviewed brought focus to expertise by indicating that a vital trait of aggressive DoD acquisition involves acute proficiency and depth concerning the application of the so-called "normal" acquisition process. In order to tailor the applicable rules of acquisition and engineering, team members must first understand what the rules are and which rules or processes apply to the current situation. People with deep roots and experience in acquisitions, contracting, finance and engineering know what the standard processes are.

They have executed large and small projects using various methods and standards. Thus, they are keenly aware of the implications from omitting or tailoring a step or the challenges in executing parallel development processes. Their expert knowledge of the proper process allows them to create a process specifically designed to meet the needs of their program.

One particular rapid organization was not 100% selectively manned. As leadership determines both the technical strengths of the team, as well as activities that bring staff personal reward, organizations can re-evaluate their internal structure. When asked how they organized the team to account for this, they stated, "We evaluate our team by the strengths and skill sets we are given. If we have to reorganize a flight to meet the skill set of the team we have, we do it. Finding out what a team member enjoys and is good at and letting them work in that area all but makes up for lack of 'handpicking' every member." In some cases, a person with the right attitude, personality, or motivation can make up for a lack of technical skill or experience. In other words, this organization was able to make up for a specific lack of knowledge and skill, by strategically leveraging the strengths of the personnel they had—even if that meant moving personnel around as projects progressed.

Besides the desire to hand select personnel, most rapid organizations required a long term commitment, particularly for military personnel. Instead of the typical two year job rotation, military members are on three to four-year controlled tours—only released for command, Professional Military Education opportunities, or other unique situations. Organizations cited a desire to keep good talent as long as possible, and influence on-the-job experience as individuals grew in their ability to execute organizational processes.

Observation 9: Maintain High Levels of Motivation and Expectations

- **Mindset: Motivated, Collaborative, competitive, impatient, creative, technical, independent**
- **Mistakes are OK, but it is not OK to repeat them**
- **Every member connected to the mission and vision**

As the research team met with rapid organizations, a certain enthusiasm was noticed abounding in the leaders and personnel—seeming to share a state of mind that was somehow traditionally military and entrepreneurial in spirit. The mindset of these individuals expressed a competitive nature born from a unique skill set, an aggressive and competitive environment, and a tangible connection to helping accomplish an operational mission. They are motivated.

Through discussion, this motivation appears to emanate from three primary sources. First, there is a direct connection to an operational community. Working closely with the end users creates both a connection to the operational task at hand and puts a face on the customer. The team is not just rushing to develop an oxygen sensor for F-22 pilots; they are developing it for Capt Josh "Tread" Saufley, so he avoids getting hypoxic on his next flight. Second, there is a sense of urgency. JUONS by their nature are "urgent" and of critical importance. Providing capability to the field may very well be a matter of survival and mission success for US military members. Finally, the rapid nature of these projects provides a tangible result not typically experienced by members of the acquisition and engineering community. Members of the rapid acquisition community have the opportunity to see the full project from concept definition, through development, and launch it into operational use. This concrete effect of seeing the fruits of labor utilized by its intended customer can be very powerful and help maintain sustained levels of motivation--even through long and arduous workdays.

A unique environmental characteristic observed in several organizations was one in which mistakes are OK, but not OK to be repeated. This concept is vital to fostering a creative, collaborative, and yet competitive environment. One specific technique observed to hone organizational skills is a "debrief culture". Originating from the operational world of reviewing a mission, focused debriefs on team performance can be extremely powerful. A debrief culture emphasizes learning from mistakes and works to identify root causes (individual or

organizational) to improve future endeavors. Furthermore, the debrief process may be applied to iterations or phases of current projects in addition to a final project debrief. The purpose of a focused debrief is to determine what went wrong and develop "lessons learned" (much like a detailed heuristic) to prevent the same errors from occurring in the next project or subsequent iterations of the current project.

The debrief culture must be established at the top level of the organization where leaders outline and enforce the expectations and importance of the debrief process. A successful debrief methodology centers on developing focus points derived from the comparison of the project's intended objectives and the actual outcome, and then investigating to determine the root causes of the focus points. To clearly maintain motivation and expectations inside an organization, each member needs to expect that a thorough debrief will be conducted with the overall goal of identifying the underlying cause of any less-than-perfect outcomes.

Observation 10: The Government Team Leads the Way

- **High level of expectations for government personnel (military and civilian) to run programs**
- **Focus on full use of government personnel capabilities – technical competence is expected**

Rapid organizations work hard to find and hire military and government experts. Government personnel are expected to run the programs, often times without a prime contractor or support contractors as part of the organization. Many of the rapid programs interviewed had a small support contractor footprint, if at all-- compared to most major acquisition programs. This is not to say they did not employ or rely on contractors to provide leadership or technical support on a large or small scale. However, when programs did have a support contractor workforce, the expectation was still the same: The government engineer, program manager, operations representative, etc., was expected to be the resident expert on the program.

These government teams are typically comprised of a set of functional experts as a development team. Core capabilities will exist on these teams – a program acquisition officer, resource/financial manager, system engineer, operational expert, safety, and test personnel. Technical competence is the standard, not the exception. It is expected every member of the team is technically able to run his or her portion of the program. They maintain awareness of activities and issues on all aspects of the development program, regardless of government or contractor responsibility. There is little room for redundancy.

In conversation with a Chief Engineer from a large program office, the following interaction was recounted: At a weekly internal program review several support contractors were briefing status with a handful of Lieutenants and Captains sitting silent around the room. One month into the job he asked the support contractors to hold their concerns and asked the Captains to brief. They could not. His question back to them was, "Why are you here?"

Observation 11: Right-size the Program-Eliminate or Reduce Major Program Oversight

- **Smaller Systems and Budgets Receive Less Oversight and are More Stable**

Budgets are often thought of as a process principle, but it depends on the context. One benefit many of the rapid program offices enjoy is a lack of size. When you are to move fast, smaller is often better. Not only do large organizations create challenges to effective management and full utilization of all personnel resources, they tend to have larger budgets. Big programs and big budgets can easily become targets for increased oversight, longer approval chains, and funding cuts. In this sense, being big creates its own problems. Size becomes its own enemy.

In this research, the size of the program budgets appeared directly related to the products themselves. The design and technologies selected to meet operational requirements directly impact the cost of the program. Sub-system product selection, interface complexity, sustainment considerations, and technical maturity all drive cost. Keep in mind these organizations are focusing on the 23-80% solution, are not going into mass production, and are not necessarily planning for long-term sustainment. However, these organizations intentionally take steps to reduce the overall size of their budgets. For example, the willingness to accept some types of risk buys down the cost of the design, development and manufacturing efforts. Costs (and risk) are also reduced by using proven or mature technology. Utilizing simple or standard interfaces can help reduce complexity—reducing development costs.

As with contracting officers, many rapid organizations have dedicated finance personnel who work to manage the cornucopia of funding sources for these projects. Imagine the variety of funding types coming into an organization that executes projects for all military branches, several 3-letter government agencies, and foreign military sales. These organizations rely on the flexibility of multiple funding types. Some customers come to them with a need, but arrive with funding from various sources or not the right color of money. It takes a special kind of organization and finance officer to understand, acquire and execute these funds.

3 DIRECT OBSERVATIONS FOR "RAPID WORLD" BEST PRACTICES (GROUP 2)

This chapter introduces those findings that reflect best practices of those organizations that "live in a rapid world." This is where the leadership and business practices drive the everyday culture.   We identify highly flexible practices across various "lanes of acquisition."

Direct Observation: Not a Single Rapid, But Many Different Flexible Rapids

3.1 LANES OF ACQUISITION

Our discussions with rapid organizations indicated a number of different definitions of Rapid, as well as a wide range of specific practices that were implemented to achieve Rapid, and various domains of product categories that aligned to what the rapid organization aimed to achieve. It was observed that various organizations appeared to focus and operate within lanes of acquisition, which could be analogous to lines of business in the commercial sector.   The lanes emerged as a result of looking at the "3 P's" seen in the initial line of questioning. Four lanes were observed, shown in Figure 3-1. They are defined at the top level by "product" type, and each has a corresponding type of "process" (from highly tailored to following every step of the DOD 5000 series) and a set of "people" attributes that work best in that particular name. Thus, there is no single ideal archetype of rapid acquisition.
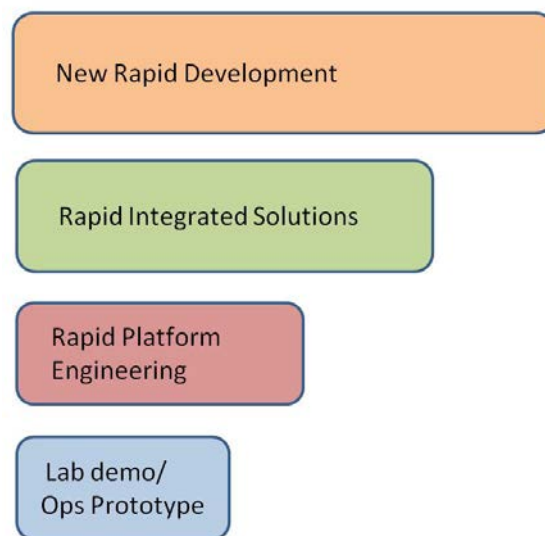
Figure 3-1: Lanes of DoD Rapid Acquisition, as Observed in RT-34

The lanes of DoD rapid acquisition we observed are as follows, based on analysis of the RT-34 site visits, and were refined against review of existing known practices within the government (both DoD and NASA):

1. **Laboratory Demonstration / Operational Prototype.** This category is an activity to rapidly design, develop, and test technologies (which can be an individual technology, component, subsystem, or integrated system), typically in a laboratory or rapid prototyping environment. The intent is to demonstrate the technology first in the lab or a test environment, with eventual demonstration in the field or to at least evaluate the demo for military utility. Evaluation can be in a realistic or simulated operational environment. Some designs may be "one-off" designs developed in the laboratory. A warfighter need may result in development of a specific technology – i.e., "technical push" – or a technology may be developed and then a warfighter need is

discovered that could use the technology – i.e., a "technology pull." The word "prototype" was discovered in the interviews to have two possible meanings. In one case, such as in the process that DARPA typically uses or in the one the Operational Responsive Space (ORS) program has used, a prototype is something developed quickly in the lab, tested in the lab, and used in warfighter operations. This is slightly different than a prototype specifically intended to be used in an operational environment, i.e., as a planned test path for a program of record. An example of the latter would be a fly-off of a new fighter aircraft prototype. The lane as defined herein is meant to consider those rapid prototypes that come out of a rapid environment and are not necessarily intended to become part of a program of record, at least not at the time that the prototypes are tested.

Lastly, this category may adapt mature technologies and/or products for military use, or integration with other military systems. The process is accelerated and tailored and includes only the necessary steps to quickly develop and field a test – for example, the process may be to: define the solution, acquire parts, build the

Push	Pull
• Industry spends years in R&D • Throws developed technology to Rapid Program • Finds user for technology	• User comes to Rapid Program with need • Collaborators with industry to find existing technology • Rapidly satisfy User need

system, test it, ship it, use it, and discard it. From the perspective of the warfighter, this would fulfill the urgent need. The people involved in laboratory programs tend to involve more researchers, PhDs, scientists, and students.

2. **Platform Engineering.** This category consists of modifying and/or integrating existing technology or technologies on top of existing platforms, with new interfaces [Muffatto, 2000]. The most predominant category discovered during the RT-34 site visits was some form of platform engineering, such as through replacement, upgrades, fixes, and enhancements to existing platforms. Platform engineering also includes repurposing of existing systems, and possibly modifying them, for different missions. An example of platform engineering is the Army Prototype Integration Facility (PIF) in Huntsville, AL, whose mission is to "support Army Aviation, Missile, DoD and technology activities in the development, fabrication, integration, test/qualification of prototype tactical and ground support systems, subsystems and components." (http://www.redstone.army.mil/amrdec/pif/about.html)

    Additionally, the PIF has capabilities that allow for the manufacture and integration of unique, difficult-to-procure, and low-rate-production items – which could fall into the category of Lab Demo per above. Another example of platform engineering is the Mine Resistant Ambush Protected (MRAP) vehicles, where the Army "approved the emergency expedient of adding armor kits to the existing Humvees because they could be fielded more quickly than the up-armored Humvees." [Lamb et al, 2009] The SE process for platform engineering is focused primarily on the interfaces and the integration of the two existing technologies and platforms, because it already has information on the existing systems. People tend to be very creative and solutions-oriented, and they have a diverse and long set of experiences with the platforms (or other platforms) that they bring to the table. A good commercial example of this is the popular television show, "Monster Garage," which takes small teams with "mechanical, fabricating or modifying expertise to transform an existing vehicle into another … such as a school bus into a pontoon boat." (http://en.wikipedia.org/wiki/Monster_Garage)

3. **Integrated Solutions**. This category focuses on the rapid creation of a new platform or system through the integration of technologies and systems. The resulting new solution changes the original intent of either (or both) the technology or original system. The process of developing an integrated solution can occur by integrating new technology with an existing system, or adding existing technology to a new system. The process may also integrate either new or existing systems in a new way, or on a new platform for a new

mission in a new context. This category differs from Major Weapons System in the level of oversight and levels of technology risk (usually lower/ more mature technology) and levels of cost; it is often characterized by major use of non-developmental items or Commercial Off-The-Shelf (COTS) components. This category may also use elements of lanes 1 and 2 to develop the new technology.

4. **New Rapid Development.** This category involves more sophisticated and complex development like traditional acquisition programs of record. Programs of record are characterized by items such as size (including dollar amount) and scope, well-defined requirements, risk level, and mission criticality.   This category may also utilize new technologies for a new platform, or a new mission in a new context, (such as the Integrated Solutions category above). The Air Force Next Generation Bomber would fall into this category. Often they include greater amounts of technology development, manufacturing and production than the other three categories.

3.2 OTHER LANE TAXONOMIES

It is interesting to note that identification and management of lanes of acquisition is a common practice. Readers should be familiar with major DoD acquisition categories (ACAT), based on R&D and Production dollar thresholds. Other taxonomies include the NASA risk classes and Operationally Responsive Space (ORS) capability tiers. DoD bases its ACAT level only on dollars. NASA attempts to capture overall risk and ORS is more concerned with schedule, i.e., time to deploy a space capability.

Operationally Responsive Space (ORS). ORS defined three tiers of achieving rapid space capability as follows. These tiers are defined by the length of time it takes to meet urgent operational needs, as requested by the Joint Force Commanders (JFC). See: http://ors.csd.disa.mil/mission/index.html and http://ors.csd.disa.mil/tier-1/index.html.

- Tier-1, "Employ," focuses on existing, on-station capabilities. This first and most effective path for providing highly responsive effects is through the employment of existing, fielded, space capabilities that could be extended, expanded, or changed beyond their original purpose to immediately apply to the urgent warfighter need. Capabilities could be delivered within minutes to hours. An example would be moving an existing satellite to a new location to immediately provide situational data to warfighters.
- Tier-2, "Deploy," is the fielding of space-ready Capabilities. The focus of activities in Tier-2 solutions is on utilization of field-ready capabilities or deploying new or additional capabilities that are field ready. This involves "responsive exploitation, augmentation, or reconstitution of space force enhancement or space control capabilities through rapid assembly, integration, testing, and deployment of a small, low-cost satellite." The goal is to responsively achieve operational status for a newly fielded capability, through the process of rapid deployment. The targeted timeframe for Tier-2 solutions is days to weeks from the time at which an urgent need is expressed. ORS developed a Rapid Response Space Center, initially collocated at Kirtland Air Force Base with existing satellite assembly and test buildings, to rapidly execute such capabilities.
- Tier-3, "Develop," is the development of new capabilities. The focus is on urgent needs that cannot be addressed with existing capabilities (Tier-1) or through the rapid deployment of field-ready capabilities (Tier-2). Once developed, these capabilities would be considered just like a "Tier 2" capability, and would be responsively deployed and employed in support of the requesting warfighter or other user. The targeted timeframe for execution of Tier-3 approaches is months to one year, recognizing that achieving such a challenging timeline requires limiting the amount of new development involved.

Tiers 1 and 2 of the ORS categories correlate most closely to the RT-34 "Platform Engineering" lane of acquisition, and Tier 3 could fall into either Lab/Prototype or Integrated Solution.

Department of Defense Acquisition Categories (ACAT). Table 3-1 defines the DoD acquisition category and the reason for its designation. The ACAT levels are based on dollars, with an implication that complexity and risk are synonymous with cost. The Milestone Decision Authority (MDA) can also designate a program as special interest. Given the thresholds seen in the RT-34 interviews, rapid programs would predominantly fall into the ACAT III category.

Table 3-1: Categories of DoD Acquisition (DoD, 2008)

Acquisition Category	Reason for ACAT Designation
ACAT 1	• MDAP (section 2430 of Reference (k)) • Dollar value: estimated by the USD (AT&L) to require an eventual total expenditure for research, development, test and evaluation (RDT&E) of more than $365 million in fiscal year (FY) 2000 constant dollars or, for procurement, of more than $2,190 billion in FY 2000 constant dollars o MDA designation • MDA designation as special interest

ACAT IA [1,2]	• MAIS (Chapter 144A of Reference (k)): A DoD acquisition program for an Automated Information System [3] (either as a product or a service) that is either:
	   o Designated by the MDA as a MAIS; or
	   o Estimated to exceed:
	   ▪ $32 million in FY 2000 constant dollars for all expenditures, for all increments, regardless of the appropriation or fund source, directly related to the AIS definition, design, development, and deployment, and incurred in any single fiscal year, or
	   ▪ $126 million in FY 2000 constant dollars for all expenditures, for all increments, regardless of the appropriations or fund source, directly related to the AIS definition, design, development, and incurred from the beginning of the Materiel Solution Analysis Phase through deployment at all sites; or
	   ▪ $378 million in FY 2000 constant dollars for all expenditures, for all increments, regardless of the appropriation or fund source, directly related to the AIS definition, design, development, deployment, operations and maintenance, and incurred from the beginning of the Material Solution Analysis Phase through sustainment for the estimated useful life of the system.
	• MDA designation as a special interest

ACAT II	• Does not meet criteria for ACAT I
	• Major system
	   o Dollar value: estimated by the DoD Component Head to require an eventual total expenditure for RDT&E of more than $140 million in FY 2000 constant dollars, or for procurement of more than $660 million in FY 2000 constant dollars (section 2302d of Reference (k))
	   o MDA designation 4 (paragraph (5) of section 230 of Reference (k))

ACAT III	• Does not meet criteria for ACAT II or above • AIS that is not a MAIS

NASA. The National Aeronautics and Space Administration (NASA) utilizes four "Classes" of missions, defined in NPR 8705.4 - Risk Classification for NASA Payloads. These classes incorporate aspects of mission priority, risk, national interest, complexity and cost. See Table 3-2.

Table 3-2: Classes of NASA Systems

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk
National Significance	Very high	High	Medium	Low to Medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, >5 years	Medium, 2-5 years,	Short, <2 years	Short, <2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted

http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8705_0004_&page_name=AppendixA

A related approach is used by NASA for launch vehicles, documented in their Launch Services Risk Mitigation Policy. Similarly, three classes (and the corresponding mission Classes) are used to assess both the cost and the attributes of the mission. Table 4.3 reflects the attributes of management, launch flight test, manufacturing audits, T&E planning, quality, and safety. Other attributes include risk.

Table 3-3: Classes of Launch (NASA)

Launch Vehicle Risk Category	Category 1 (High Risk)	Category 2 (Medium Risk)		Category 3 (Low Risk)		
Payload Class (per NPR 8705.4)	D	C&D, sometimes B		A, B, C & D		
		Alternative 1	Alternative 2	Alternative 1	Alternative 2	Alternative 3
Management Systems	AS9100 or ISO 9001 Compliant	AS9100 Complaint	AS9100 Complaint	AS9100 Compliant	AS9100 Compliant	AS9100 Compliant
Flight Experience	No previous flights required, can use the first flight of a common launch vehicle configuration, instrumented to provide design verification & flight performance data Post-Flight Operations/Anomaly Resolution Process Flight Data Assessment Process	1 successful flight of a common launch vehicle configuration, instrumented to provide design verification & flight performance data Post-Flight Operations/Anomaly Resolution Process NASA Flight Margin Verification	3 (minimum 2 consecutive) successful flights of a common launch vehicle configuration, instrumented to provide design verification & flight performance data Post-Flight Operations/Anomaly Resolution Process	14 consecutive successful flights (95% demonstrated reliability at 50% confidence) of a common launch vehicle configuration, instrumented to provide design verification and flight performance	6 successful flights (minimum 3 consecutive) of a common launch vehicle configuration, instrumented to provide design verification and flight performance data Post-Flight Operations/Anomaly Resolution	3 (minimum 2 consecutive) successful flights of a common launch vehicle configuration, instrumented to provide design verification & flight performance data Post-Flight

		NASA Flight Margin Verification	data Post-Flight Operations/Anomaly Resolution Process NASA Flight Margin Verification	Process NASA Flight Margin Verification	Operations/Anomaly Resolution Process NASA Flight Margin Verification
Design	NASA assessment of LSC design reliability	NASA assessment of LSC design reliability	NASA assessment of LSC design reliability	NASA assessment of LSC design reliability	NASA assessment of LSC design reliability	NASA assessment of LSC design reliability
Mfg & Ops and Systems Engineering	NASA Audits Documented ICD Process	NASA Audits	NASA Audits	None	NASA Audits	NASA Audits
System Safety	FMEA for all safety critical component Preliminary & Final Hazard Analysis Compliance with applicable Range Safety Requirements	Demonstrated compliance with applicable Range Safety Requirements	Demonstrated compliance with applicable Range Safety Requirements	Demonstrated compliance with applicable Range Safety Requirements	Demonstrated compliance with applicable Range Safety Requirements	Demonstrated compliance with applicable Range Safety Requirements
Test & Verification	Acceptance Test Plan in place Ground Test, End-to-End Tests complete	Comprehensive Acceptance Test results	NASA Design Certification Review	None	NASA Design Certification Review	Comprehensive Acceptance Test results
Quality Systems/Process	NASA Audit	NASA Audit	NASA Audit	None	NASA Design Certification Review	Comprehensive Acceptance Test results
Flight Hardware & Software Qualification	Qualified Hardware (for space application) Testing completed	Series of NASA Engineering Review Boards on vehicle subsystems	NASA Design Certification Review	None	NASA Design Certification Review	Series of NASA Engineering Review Boards on vehicle subsystems
LV Analysis	Analysis Plan/Definition	Analysis Plan/Definition NASA Coupled Loads Analysis IV&V	NASA IV&V	None	NASA IV&V	NASA IV&V
Risk Management	Risk Plan, Mitigated and Accepted Technical and Safety Risks	Risk Plan, Mitigated and Accepted Technical and Safety Risks	Risk Plan, Mitigated and Accepted Technical and Safety Risks	Risk Plan, Mitigated and Accepted Technical and Safety Risks	Risk Plan, Mitigated and Accepted Technical and Safety Risks	Risk Plan, Mitigated and Accepted Technical and Safety Risks
Integrated Analysis	None	None	None	None	None	Full Vehicle Fishbone
Launch Complex	None	NASA Engineering Review Board	NASA Design Certification Review	None	NASA Design Certification Review	NASA Engineering Review Board

http://nodis3.gsfc.nasa.gov/NPD_attachments/N_PD_8610_007D_A.pdf

Observations. There are interesting connotations and observations by examining these rapid lanes. Lane et al {{189 Lane, J. 2010}} in their study of rapid acquisition success factors, offered that the processes and personality types may also differ across types of rapid environments. Laboratory prototyping may have less structure, more innovation and trial-error experimentation. Integration solutions may have more formal processes with greater lifecycle considerations (and the people to consider them). This is further reflected in Finding 4.2.

3.3 Flexibility Exists Within and Throughout All Lanes

Maybe this finding is not surprising - there is huge flexibility both within and across these lanes of acquisition. This flexibility involves people (hiring) and process.

3.3.1 Flexibility in Hiring the Right People

There was an overwhelming response from the interviews on the importance of people in expedited SE and urgent needs projects. For example, the right people could execute any process; but a process alone without the right people does not guarantee success. Some of the key comments from interviews include the desire for small, handpicked teams; selection of the "A" team or "a team"; and ensuring a mix of diverse experiences.

One of the first site visits was with an Air Staff rapid acquisition office. They were highly selective in bringing in civilians and military into this organization. It was mentioned that, "they interview 100 to hire a few." Generally this is a unique situation for large program offices, where personnel, both military and civilian get assigned through normal rotations. Another organization mentioned the use of "recommendations." They, too, were highly selective and if a trusted member (such as a past employee) recommended someone, that recommendation was as good as an interview.

Another aspect that was important regarding personnel selection was personality type. In almost every case, these lean, agile, rapid organizations were looking for highly motivated and competent government employees. These people were comfortable with uncertainty and flexibility of process. Interesting to note, not all of these rapid team members can be same. One organization mentioned they had "5 Tiggers and 1 Eeyore" (reminiscent of the characters in "Winnie the Pooh"). You need to have a "naysayer" to ensure you don't run *too* rapid, without missed critical considerations.

Another organization, as mentioned in Group 2, previously had the ability to selectively choose personnel, but now receives personnel through the normal rotation. As a result, they were no longer able to pre-select personnel according to specific skill needs or personalities. Instead of fretting about this change, the organization instead changed its strategy to where it annually evaluated the mix of personnel, based on their competencies, skills, experiences, and desires. Then they defined the portfolio of work the organization was capable of achieving in a given year, based on that mix of personnel. This was a very innovative way of making real-time adjustments to capability based on personnel.

Regardless of who was selected or desired for an organization, military organizations have the further challenge of adjusting head count and skill mix when personnel are deployed. This often leaves gaps that cannot be filled easily.

3.3.2 Flexibility in Process

Process variation was another area that was used to achieve flexibility – especially in contracting – but also in management and SE. The theme of flexibility arose repeatedly in the SME discussions, with organizations often detailing the contracting approach they used and how this facilitated (or hindered) the ability to execute rapidly. The application of flexibility was also dependent on the experiences of the technical personnel involved. Flexibility and risk go hand in hand, so it is important to manage both.

For example, one organization had a several year IDIQ contract to rapidly add tasks for local on-site design and production services. These included welding, machining, cable assembly and checkout, breadboard fabrication, install, test etc. Interestingly, these services were performed in government-owned, government operated (GOGO) facilities.

Other contracting approaches, used by this organization and several others, including classified organizations, provided access to subject matter expertise through several sole-source contracts. This allowed immediate access to a pool of uniquely qualified and pre-identified set of individuals that could be rapidly requested to perform work as needed. Competition was also used, depending on the type of work involved (e.g., execution of a build to print item), the expertise required (e.g., was it unique or were there multiple qualified sources), and the personnel and contractors involved. Even when competition was used, the entire program understood the need to proceed quickly, such that award and delivery of weapon systems could be done in several months (not years).

The choice of contracting instrument was often based on the experience, preference, and "comfort level" of the contracting officer. Contracting officers who were embedded in rapid organizations typically had the most knowledge of the flexibility available in existing DoD policy and Federal Acquisition Regulations (FARs). But most often, flexible contracting practices are not well-known, trusted, understood or utilized because they are not the approaches used in traditional acquisition – or they may not be appropriate – and therefore contracting personnel are not familiar, nor comfortable with working with new and different mechanisms. Examples of flexible contracting mechanisms include: fixed price contracts, IDIQs, sole source, commercial terms and conditions, waivers (such as for certified cost and pricing data), FAR Part 12 commercial tailored contracts, Other Transaction Authority (OTA), and NASA Space Act Agreements (SAAs, i.e., NASA's form of an OTA).

DARPA uses "Other Transaction Authority" in its rapid development programs. OTAs are fixed price, milestone based contracts, with no FARs and only the minimum statutory terms included. This is a very friendly way to rapidly get on contract, especially for small businesses, entrepreneurs, or other non-traditional contractors. The Missile Defense Agency (MDA) also has OTA authority. Another mechanism is FAR Part 12 commercial tailored contracts. "FAR Part 12" is used to procure commercial items on a fixed price basis. In an attempt to educate contracting and personnel about how to use FAR Part 12, a "Consistency in the Acquisition of Commercial Items," memo was issued by the Undersecretary of Defense for Acquisition, Technology & Logistics [USD (AT&L)] in July 2001, followed by a "Commercial Item Handbook," in November 2001.

NASA has more recently used contractual flexibility with the activities involved in commercial cargo and crew for the International Space Station (ISS). SAAs were used in the initial development process, with highly tailored management, engineering, and test processes. The intent is to use FAR Part 12 to procure the actual commercial services from commercial entities.

The RT-34 discussions also revealed tailoring and scaling processes for systems engineering and program management, depending on what product was being developed (i.e., what the research came to call the lane of acquisition) and who was working on the program (i.e., the level of experience, capabilities, and competencies of the individuals and the combined team). The results show that rapid organizations first defined what it is they are trying to accomplish, and then they define the scope of the effort to match the time available. The team determines the "most important" SE and program management artifacts needed, and develop a program plan with a timeline and milestones that match the level of effort. As seen in one organization, this process was described as a "mini, compressed" equivalent of a DoD 5000 series, scaled down to only the necessary milestones and minimal reviews appropriate for that particular urgent need.   The focus was on execution, and the minimum amount of paperwork, meetings, and oversight to accomplish the task.

The ability to tailor in this way may depend on the organization using elements of the Level 2 framework, such as "intense knowledge sharing" (e.g., frequent communications to keep the team on the same page at all time without artificial reviews conducted for review sake, or embedding the warfighter with the developer) and a risk-based culture. An example of the latter is that the ability to tailor requires the judgment calls of experienced personnel, who have the scars to show for many previous programs and scenarios, which is then used to make decisions and evaluate risk at any given time in the program.

3.4 ENABLERS TO GROUP 2

Similar to Groups 1 and 3, the Rapid Best Practices observed in Group 2 may also be facilitated by new tools and information technology. Tools that help intensive knowledge sharing will facilitate real-time management. Other tools, such as the COCOMO parametric suite of cost and schedule estimator, can be used throughout the rapid lifecycle. See Appendix D for further details.

4 INFERRED ORGANIZATIONAL CHARACTERISTICS FOR "GO FAST" CULTURAL BEST PRACTICES (GROUP 3)

In this chapter, we inferred additional findings from the interviews and literature review that are specifically focused on expedited processes supported from across the enterprise. We refer to these as "go fast" cultural best practices. Here is where rapid organizations really start to "go fast" and differ from traditional acquisition programs. There are cultural shifts in the organization from top to bottom. From this analysis, we offer 3 findings. The findings include knowledge sharing, a risk-focused culture, and the organization's ambidexterity (plan/execute) abilities. It also includes an ability to employ real-time management, from top to bottom. These "go fast" concepts are all cultural best practices that traverse work units, functional partitions and project groups.

The Inferred Characteristics are:
- Intense and efficient knowledge-sharing is used to enable stabilization and synchronization of information
- Rapid organizations are characterized by a risk culture
- Rapid organizations are structured for ambidexterity
- Rapid DoD acquisition employs real-time management.

4.1 INTENSE AND EFFICIENT KNOWLEDGE-SHARING IS USED TO ENABLE STABILIZATION AND SYNCHRONIZATION OF INFORMATION

Rapid organizations repeatedly mentioned the need for intense and efficient knowledge-sharing. The knowledge sharing had a particular purpose: for synchronization and stabilization of information. Synchronization was needed because, in a rapid work environment, information is often entering the program or project at such a speed to different personnel that it is necessary to determine if everyone knows the same information, and if they don't, are caught up. Otherwise, decisions will be made based on obsolete or incomplete information. Stabilization of information is also critical, particularly prior to decision-making – even if the stabilization is temporary – so that the evidence for the decision is clarified, vetted, and then appropriately used in the short time available.

Such continuous and intense knowledge-sharing could have the adverse effect of slowing rapid teams. However, in our discussions, the organizations found ways to make the intense knowledge sharing as efficient as possible. Several of the interviewees mentioned that collocation was helpful for fast knowledge-sharing because it allowed people to easily inform others spontaneously of new information. In fact, collocation was mentioned thirty times. This enabled everyone to have access to the project, with constant updates on all project areas, and facilitated constant integration of those different project areas. One organization in particular would bring customers on-site during the requirements development phase to speed up the requirements phase and get a contract in "20 days vs 1 year."

In these cases, collocation was also used as a way to interface with the user as early and often as possible. When the warfighter was collocated with the design team, even for a partial time, the team was able to more quickly discern what the warfighter actually needed and do rapid trades to get to an efficient solution.

Collocation, however, is impractical in those many situations in which the group is larger, temporary, distributed, or involves members who travel a fair amount. Moreover, intensely sharing information via collocation also leads to significant disruptions, making it more difficult for individuals to complete the task at hand. While alternatives to collocation were not often mentioned, in one case, a project management dashboard was used to efficiently share knowledge to all program members on the status of the projects, and in another case, a new chatroom had been started to facilitate knowledge-sharing.

Collocation also may not be needed if the context of the work and the construct of the team can achieve the same result. For example, one commercial software team that practiced agile software development explained that collocation was an insult to them. The design team had worked together for 25 years and each knew all elements of the legacy software. They thrived working under their own work habits – one liked to work early, another stayed up all night, a third liked to work from home. The closeness of the team and their knowledge of the product and of each other meant that they had built extreme trust and they had different ways of achieving the knowledge transfer that collocation is often sought to provide.

We observed that collocation was one example of "how" organizations rapidly shared information and other techniques including "digitally enabled" tools, as further explored in Appendix D. The bottom line is that organizations recognized the need to have constant and equal access to information and the ability to turn this into usable knowledge; how they did this varied, and may depend on the acquisition lane, circumstance, environment, culture, or access to information technology tools.

4.2 RAPID ORGANIZATIONS ARE CHARACTERIZED BY RISK-FOCUSED CULTURE

Consistent across the rapid organizations was a characteristic that we have labeled: "a risk focused culture." By culture, we refer to the norms that permeated the organization and the overarching focus of personnel as they went about their work. We refer to this culture as "risk-focused" because it was one of confronting, identifying, and understanding risk, deciding to accept it, mitigate it or remove it, then moving forward and monitoring the risk. There was a constant awareness of the risks involved. In fact, risks were seen as normal aspects of their work. In rapid cultures, each person's job has risk components to it, and each person is expected to exercise appropriate discretion in confronting, identifying, sharing, mitigating, and accepting the risks. For example, a financial contracts officer may need to accept some risk in moving quickly to resolution on getting money creatively to the team. The rapid organizations, then, were not trying to eliminate all risks, since there seemed to be recognition that such an attempt would be foolhardy. Instead, they were accepting of riskiness of what their work involved and understood the context of the risk.

Accepting risk did not mean inaction or fear. To the contrary, accepting risk meant that personnel in rapid organizations were constantly engaged in thinking through contingency plans, identifying and exploring root causes of the risks in hopes of diverting the risk, and monitoring the risks so that mitigation actions could be taken if need be. In some cases, it was enough to be aware of and accept (take) the risk.

Dedicated Contracting Office
• One organization cited importance of dedicated contracting division • Otherwise, rely on base contracting and hope to get the same person on the phone each time • Have them set everything aside • Keep paperwork in project folder • Speed contracting process-10 days instead of 11 • Not rapid, but faster

For example, one organization developing prototypes found their prototype had an immediate application for a warfighter and could be used in the field for an operational purpose earlier than expected. However, there was no time to include a safety feature that was planned for later in the development process. The risk of sending this prototype in the field without the feature was mitigated because the particular warfighter was experienced, made aware of the risk, and understood how to use the prototype without that feature. This risk was worth taking. The team (consisting of the rapid organization and the end user warfighter) mutually agreed to send the product into the field without the feature. On the other hand, had the warfighter been inexperienced or not knowledgeable of the risks involved with using a system without this feature (such as an 18-year old soldier fresh out of boot camp) then it may not have been appropriate to send the prototype into the field at that time.

Research on risk-focused cultures in industry has repeatedly demonstrated that they are only possible when management fosters a "climate of psychological safety" (Edmondson et al 2001). A climate of psychological safety involves leadership offering "topcover" (i.e., supporting the personnel when criticized by external parties) to their personnel as well as management expectations backed by an incentive reward structure for personnel to point out risks, take risks, accept risks, and mitigate risks with the expectation to understand and be fully aware and transparent of what risks are where and why. In other words, the reward system must also match the risk culture. Personnel do not get fired for taking a risk or making a mistake. This culture is created when learning, story-telling, and mentoring are encouraged and practiced and both successes and failures are shared such as to avoid making the same mistakes twice.

4.3 RAPID ORGANIZATION ARE STRUCTURED FOR AMBIDEXTERITY

In corporate contexts, we are increasingly observing the presence of what are referred to as "ambidextrous organizations" (Birkinshaw and Gibson 2004). Ambidextrous organizations have two different structures in place: one structure focuses on exploration, and another that focuses on exploitation. The structure focused on exploitation generally has substantial routines in place, including milestones, project management practices, and specific work activities identified that should be performed in particular order. Personnel working in exploitation structures tend to be rewarded for knowing the rules and following standard processes. The expectation conveyed by management to personnel working in an exploitation structure is take the product and process as given, with a focus on "efficiently executing to plan".

In contrast to the exploitation structure, the structure focused on exploration generally encourages entrepreneurial spirit, innovation, experimentation, learning, iteration, and risk. The expectation conveyed by management to personnel working in an exploration structure is that the product or process is not given, but needs to be changed in ways not initially anticipated. Personnel working in exploration structures tend to be rewarded for taking risks, generating new information or technologies, and creating new opportunities for the program. Such personnel tend to be explorers themselves, comfortable with ambiguity, uncertainty, and challenges that may or may not be known or resolvable.

"Multi-Lingual" Personnel
• One organization cited importance of employees with broad experience
• Prioritized that everyone be multi-purpose
• "Speak two or three things"
• Not just in their own box

In a corporate context, exploration structures may describe the early concept development phase, while exploitation structures may describe the implementation or operational phase of an activity. However, in a truly ambidextrous organization, both structures are able to be invoked at any point in time depending on the needs of the customer or new information received from outside the organization that suggests a requirement to switch from exploration to exploitation or visa-versa. For an ambidextrous organization to be able to switch between exploration and exploitation, personnel and routines need to be in a place that they are able to know when to switch and how to switch. An ambidextrous organization, then, will separate personnel by those who are comfortable in exploration modes and those who are comfortable in exploitation modes, and will also have personnel who are comfortable in both modes, as well as sufficiently experienced and self-confident to make judgments about when and how to invoke the different modes. An example in corporate contexts is a product development manager who is both working to get a product out as well as working on new high-risk R&D.

We observed several of the rapid organizations exercising this ambidexterity. On the exploration side, there was a constant exploring to anticipate future need. They wouldn't simply respond to a warfighter's statement of need, but instead would explore what the problem was and generate new ideas to help the warfighter achieve the end objective. Moreover, the rapid organizations we interviewed were not simply exploring, but finding ways

to explore faster. The exploitation structure existed as well, as there were milestones, project management practices, and deliverables expected. Finally, the rapid organizations were able to switch practices quickly. For example, in one organization, an urgent need by the chain of command quickly converted the lab project into a fielded demo; likewise, an urgent need often triggers a variety of platform modifications.

Ambidexterity also is seen in the dictionary context of highly skilled, adept people who are equally expert at both hands. These multi-lingual personnel tend to have broad experience in many areas and are capable of working multiple jobs. Several organizations talked about the having people on their teams that were capable of serving in multiple roles. For example, engineers who had rotated through acquisition jobs had a greater appreciation and knowledge of budgeting and contracting. These were true systems thinkers who could solve problems and contribute to multiple domains, given the depth and breadth of their experience.

In switching rapidly between exploration and exploitation, we observed a concern expressed by the managers, that we describe "technical debt". A term from the agile software development community, "technical debt" is a metaphor for work or rigor not accomplished, often in one dimension of a program (like architectural simplicity, modularity or use of commercial off the shelf (COTS) systems, often to meet an urgent need or schedule deadline.) These compromises often have to be paid back, eventually, and often with "interest" for the long-term stability and success of a program that is intended to have a long life cycle.

Programs of Record: Just Off Rapid's Flank
• Important to have a competent government Team
• One organization employed prior and currently enlisted project members
• Stay close to user/warfighter
• Constant communication
• Constant focus on "off ramp"
• Program in use longer than a year rolled into Programs of Record
• If less than year-focus on rapid fielding; work out off ramp later

As rapid organizations move quickly, the decisions they may or may not come back to haunt them, and they often do not know which of those decisions are the ones that will come back. There may be areas where rapid development takes more time up front to consciously make decisions that lead to a system architecture that is sustainable in the long term, if that is desirable.

4.4 RAPID DoD ACQUISITION EMPLOYS REAL-TIME MANAGEMENT

A unique characteristic of the DOD vis-à-vis corporate contexts is the opportunity that young people in the military are given to learn, accept substantial responsibility, and gain experience in making decisions under uncertain conditions. The researchers found in the site visit discussions, that the rapid organizations were managed in a manner that explicitly provided these opportunities. Personnel were empowered to learn, understand and accept responsibility for the risks they incurred, and were expected to make decisions about acquisitions, despite not having complete information. While all DOD contexts encourage empowerment at the lowest level, rapid organizations face the additional challenge that the empowerment needs to be done in real-time.

We also discovered that the empowerment was more than just a management fad. It requires the right people with the right skills and experiences, in the right culture and decision making environment, to thrive.

A risk-focused culture, intense knowledge-sharing, and having both exploration and exploitation structures in place (also part of Group 3) supports the empowered individual, however, the researchers found that these rapid practices were not the only building blocks of Group 3, the "Rapid World" Best Practices. Two additional characteristics of decision-making were required for the personnel to be sufficiently empowered to act effectively in a rapid environment: forward-focus and an urgent decision process.

4.4.1 FORWARD-FOCUSED THINKING

The researchers saw managers and engineers closely focused on future milestones that would quickly inform them when the team was veering off course. One example of forward-focused thinking observed in the interviews was that progress toward test and test plans were discussed even though a team was still quite early in concept formulation discussions. Another example was that deployment specifics were being mentioned in casual conversations as new design ideas were expressed. Yet another example is "situational awareness of the user", i.e., the extent to which rapid personnel were close enough to the user group (such as a warfighter) that they knew about the latest information from the war zone or were confident that they could anticipate how the warfighter was likely to react to a new idea. Thus, empowered personnel were not simply empowered to make a decision, but, as they were making the decision, they needed to be able to articulate the downstream implications of that decision, and then adjust their decision-making accordingly and in real-time.

An important aspect of forward-focused thinking was the collective nature of the thinking. Observations were both shared with other project members (as part of best practice in level 2), and were also interpreted among the team members for the appropriate meaning and application. Thus, empowered personnel were not necessarily or exclusively empowered to act alone, but rather to act after a collective interpretation.

One organization articulated its forward thinking process at the enterprise level, as shown in the box. The leader mapped out a process that showed the path a technology took from design to the lab to development to test to operations – in other words, he mapped out the lifecycle of a technology. The intent was to always address the question of whether a technology would fulfill a current warfighter need requested in one or more JUONS, whether it could meet a future anticipated need, whether it would be an enduring need on its own, or whether it could be transitioned (sooner or later) into a program of record. This enterprise perspective allowed the organization to constantly evaluate the maturity and application of the technology or system, and to anticipate opportunities to transition. Increasing levels of SE rigor could be included if the technology was going to experience a longer lifecycle, with the requisite "ilities" of a traditional program.

> **Forward-Thinking Process**
>
> One Organization's four question survey for finished technologies:
> 1. Who else can use it?
> 2. How else can it be used?
> 3. What does this enable next?
> 4. How could this be used against us?
>
> The organization was constantly looking to whether the rapid solution would apply to one or more urgent needs statements, and whether it could transition to a Program of Record. The users were always looking for "what's next?"

4.4.2 URGENT DECISION PROCESS EMPOWERMENT

In a DOD context, often individuals may not have the sole authority to make a decision; the decision needs to be made at the appropriate rank. Thus, empowered individuals are often in a situation in which immediate action is needed but they alone are not able to make that decision. Thus, empowered individuals, to act quickly, must often make several decisions: decide *if* action is really needed urgently, decide *who* has the authority to make the decision, and decide *how* to get the decision made as quickly as possible. Through forward-focused thinking, the empowered personnel seemed to be confident in their ability to make the first decision: decide if action is really needed urgently. The second decision – who has the authority to make the decision – seemed to be particularly facilitated by DOD rapid program managers.

These experienced managers appeared to have a sufficiently detailed understanding of both the authority to which they could delegate decision making, and which people would have the right experiences and knowledge to make the decision at the lowest possible level where that knowledge was available and could be acted upon. The leadership also had confidence that their people had the skills, experience, context, ability, and confidence to

make an appropriate decision in the time available with the knowledge available. Often, the difference between a right and wrong decision may not be known immediately; everyone understood (per the "psychology of safety" described earlier) that a "wrong" decision would not be punished and rather would be learned from. The measure in a rapid program is always time: making decisions in an expedited manner to keep the rapid development process going.

Personnel in the program would often quickly access these experienced program managers to get rapid advice on who has authority to make a particular decision. Finally, the empowered individuals needed to decide how to facilitate having the decision made when they personally and individually could not make the decision. The interviews indicated a variety of different methods used to get a decision made, including collocating near the highest chain of command. One interviewee discussed the importance of collocation and information sharing saying, "he was "61 steps from any program manager and 123 steps from the PEO's office".

We also observed an organization where empowered decision making failed. In this example, a rapid team was established, using many of the standard Kelly Johnson Skunk Works philosophies that they were told would enable expedited development: small team, collocation, empowerment, and freedom from bureaucracy. Decision making was pushed to lower levels, as the senior leaders thought this was a "benefit" to the team, would create a motivated work force, and would facilitate faster and better decision making. The opposite happened. The team "froze" because this empowered gift was too far outside the known culture and its behaviors, and they were paralyzed with inaction. For example, the team members expected to be given a set of known and validated requirements upon which they could begin their systems engineering process. The senior leaders didn't know if the problem was with the team members or the team leader. An independent review board recommended replacing the team. Ultimately the group leader remained and the entire team was replaced as the organization guessed (correctly) that a different mix of personalities and experiences was necessary to thrive in this environment. The new team consisted of individuals with a broader set of experiences, who appeared to be comfortable with managing risk and uncertainty, had demonstrated innovation on previous projects, and who were eager to be part of an innovative new approach. This example shows the challenges in just following a "script" for enabling rapid development, and that there is a deeper integration of people, process, and product and this integration is within an overall culture of rapid.

4.5 ENABLERS TO GROUP 3

Aspects of this Go-Fast Culture may also be enabled by creative and effective use of information technology (IT). While not the focus of our guiding questions for the subject matter experts, some findings from the literature and observations at a few organizations suggest new IT tools may facilitate Group 3 characteristics. Appendix D introduces such techniques as collaborative workspaces and living team rooms, social media techniques, and organizational and systems engineering assessment tools.

It is important to note that the mere existence of such tools does not guarantee that the team members will use them effectively, or at all. A culture and discipline goes along with the tools – if people believe, and can demonstrate, that the tools make their lives easier, they are more bound to use them. For example, one team used Sharepoint to post updates on the project. However, once they realized that the latest versions resided not on the shared drive but were hoarded on individual computers, they stopped going to Sharepoint and instead went to individuals to find information. This defeated the purpose of a collaborative, shared space where everyone had access to the same information at the same time and could create knowledge from that data.

The RT-34 research team practiced its own collaboration using DropBox, weekly telecons, and emails. We discovered the most dramatic progress occurred when the team met in person for an extended time. This could be due to human nature and/or because we had focused time without distraction on the research.

5 CONCLUSIONS AND FUTURE RESEARCH

5.1 CONCLUSIONS AND RECOMMENDATIONS

The following framework captures all Observations, Findings, and Recommendations, across all groups.
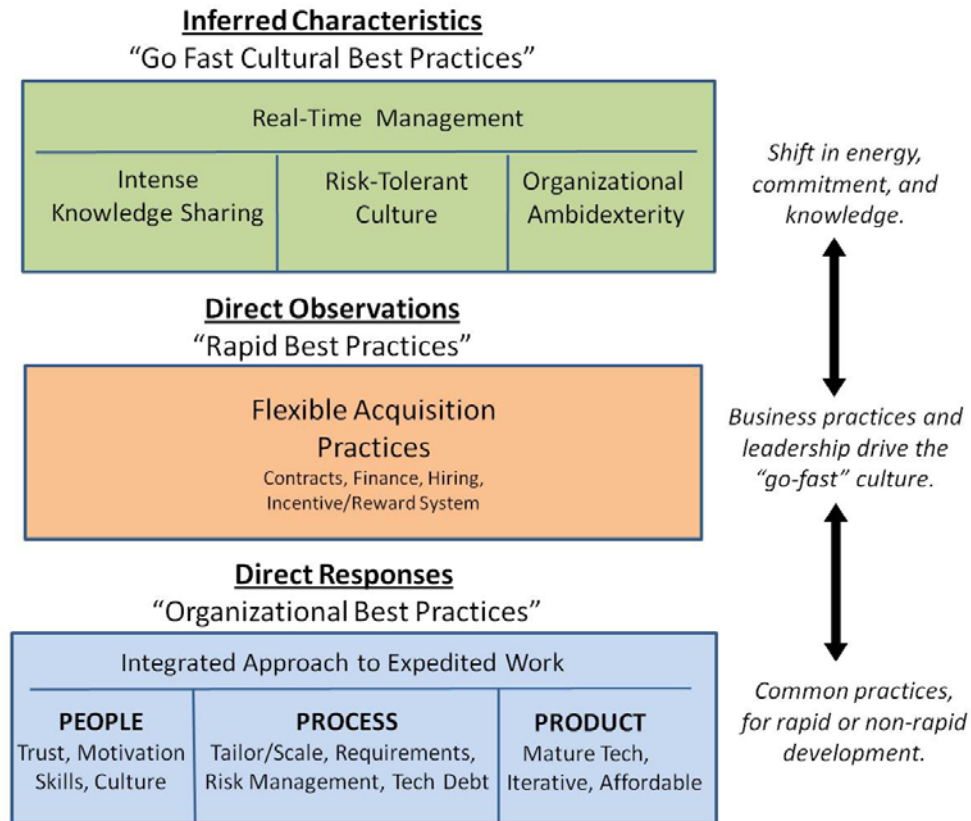
Figure 5-1: RT-34 Expedited SE Framework

Group 1: Direct Reponses (Organizational Best Practices)
1. Use Mature Technology – Focus on the State of the Possible
2. Incremental Deployment (Development) is Part of the Product Plan
3. Strive for a Defined Set of Stable Requirements Focused on Warfighter Needs
4. Work to Exploit Maximum Flexibility Allowed
5. Designing out All Risk Takes Forever…Accept Some Risk
6. Keep an Eye on "Normalization"
7. Build and Maintain Trust
8. Populate Your Team with Specific Skills and Experience
9. Maintain High Levels of Motivation and Expectations
10. The Government Team Leads the Way
11. Right-size the Program - Eliminate or Reduce Major Program Oversight

Summary Observation – Group 1: Rapid requires an integrated approach: People making judgments, Processes for task reductions, and Product aspects focused on rapid objectives.

Group 2: Direct Observations ("Rapid World" Best Practices)
- Not a single Rapid, but many different flexible Rapids, with flexible acquisition practices.

Group 3: Inferred Characteristics ("Go Fast" Cultural Best Practices)
- Rapid DoD Acquisition Requires Real-time Management
- Intense and efficient knowledge-sharing is used to enable stabilization and synchronization of information
- Rapid organizations are characterized by a risk-focused culture
- Rapid organizations are structured for ambidexterity - one structure focuses on exploration, and another that focuses on exploitation.

Recommendations
Based on the above observations and findings, the following are the RT-34 recommendations.

1. Ensure that projects utilize prioritized organizational and project best practices
2. Train program managers, engineers and contracting officers in organizational and cultural best practices, real-time management approaches, and the different flexibilities that exist.
3. Encourage programs to intensively share knowledge, have a risk-focused culture, and create an ambidextrous organizational structure
4. Share knowledge, experience, mechanisms and lessons learned across programs and organizations
5. Quantitatively monitor progress in expediting SE processes, and use the measurements to improve both schedule acceleration and the ability to estimate it
6. Use DOD rapid organizations as a testbed to introduce digitally-enabled solutions
7. Develop the acquisition workforce using rapid programs to provide full lifecycle insight and hands-on experience.

In addition, we have added some observations and findings, not just from SME discussions, but from commercial best practice and academic research; these include aspects of IT solutions and systems tools. See Appendix D.

5.2 PHASE 3 PLAN TO VALIDATE FRAMEWORK (CONSIDERATIONS FOR PHASE 4 IMPLEMENTATION)

As was the RT-34 research original plan, some form of implementation of the framework should be proposed to analyze the framework in action and iterate it based on observations and results as applied to a real DoD acquisition program. Phase 3 proposed to prepare a plan for both validating the framework on a DoD acquisition program, or plan for follow-on research. The actual execution on a real DoD acquisition effort was referred to as the unfunded Phase 4 effort. Also at this point in RT-34, we are now better positioned to articulate follow-on research, based on the site visits, data analysis, observations and findings.

While executing Phase 1 and 2 of this RT, the *how* and *where* an Expedited SE Framework could best be demonstrated was continually discussed by the team. During the site visits, the team assessed interest on the part of organizational leaders to advocate for a rapid pilot study.

The following list may suggest the diversity of possible organizations (and subsequently) the lanes of acquisition that the SE Expedited Framework could be applied:

- CubeSat Generational Development (Space Development & Test Wing; Operationally Responsive Space office, Kirtland AFB, NM)
- Predator ISR Innovations (HQAF/A2Q, Creech AFB, NV)
- MicroUAVs (Eglin AFB, FL /Univ of Florida)
- U.S. Navy Ohio Class Submarine

- U.S. Army Helicopter
- F-35 Avionics upgrade (JSF Program Office)
- AFRL Laboratory prototyping /ops demonstration effort
- GPS, next block or shadow competition of currest closk.
- USAF/SMC program, incorporating Aerospace Corp Lessons Learned from ORS
  - Combined with recommended use of Aerospace Concept Design Center (CDC)
- AF Next Generation Bomber (Air Force Rapid Capabilities Office)
- AF Reusable Booster System (WPAFB, OH)
- Ideas to be solicited and/or performed at Army PIF in Huntsville.

5.2.1 APPROACHES TO IMPLEMENTATION

The researchers do not expect that an existing program will simply pick-up and apply the framework completely. Perhaps, though, parts can be lifted and applied judiciously. While the next "big" program could be chosen for a non-traditional, rapid approach, such as the new long-range strike bomber managed from the Air Force RCO the framework could also be used in a mixed (hybrid) approach. Figure 5-1 shows three such approaches.

Using the next acquisition program that is beyond Milestone A or entering Milestone B, simply compete a smaller rapid, more innovative approach simultaneously. See Figure 5-1 (a). With recent emphasis in DoDI 5000.02 and the Weapon Systems Acquisition Reform Act (WSARA) on competition prototyping (DoD, 2008; US Congress, 2009), this approach is particularly attractive. Let small business and entrepreneurs apply their techniques simultaneously to an existing program of record. There is no expectation of "getting something for nothing", but rather there is an important tradespace of schedule driven development with capability/ requirements.

A modification to this approach is captured in Figure 5-2 (b) where the use of a rapid approach is done while a larger program of record (either new or existing) is the long-term planned transition strategy. The rapid solution would be integrated at a strategic time. This approach was observed already during several interviews, where rapid offices were looking for follow-on partnerships or program integration opportunities.

A combination of the two prior concepts produces approach (c) called "Compete with Integrate". Like (a), competition fuels the expedited schedule and innovation, and like (b) there could be one or more opportunities for strategic integration. But this approach continues to iterate the rapid solution, as is best practice. This allows either the original program of record to devolve, the rapid iterations to continue as needed and stopped once the capability gap is adequately filled.

a. Compete ("fly-off")   b. Planned transition   c. Compete with Integrate
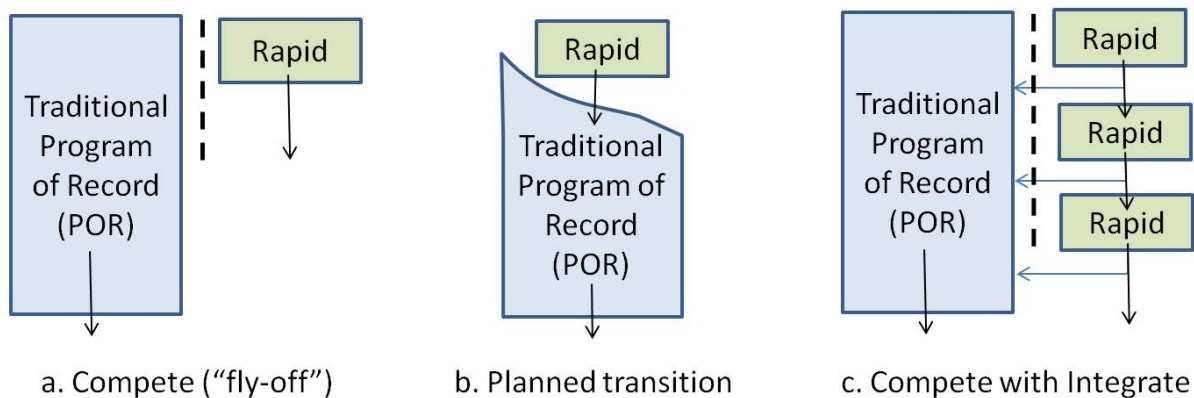
Figure 5-2: Approaches to RT-34 Framework Implementation

5.2.2 THE CHALLENGE OF PROGRAM CHOICE

The Phase 4 research could focus the RT-34 "rapid solution engineering" on the highest payoff approach, rather than small incremental change. While more risky, this approach has the potential to make a big difference *by demonstration* in a manner that is irrefutable, while a less ambitious project's result will likely be lost in irrelevance. A prudent and conservative approach would be to select a rapid hardware demonstration project that is easy to achieve, low-cost and inoffensive. But this may lead to the irrelevance mentioned above. If the chosen demonstration is in fact easy to get approved and funded, and is acceptable to the entrenched and competing conventional acquisition bureaucracies, it necessarily must be a project that, once successfully concluded, will be easy to ignore. The response will be "…sure you can do rapid prototyping on a small project, but the project can't be…" – pick one – "scaled up" or "put into production" or "produce meaningful results for the warfighter."

Trying not to be pessimistic, the researchers point out the dozens of rapid projects developed by Scaled Composites over the past thirty years, and note the sad fact that essentially none of them have actually seen production or field use, either military or commercial. Each project was successfully accomplished, generally within schedule and budget, but translation has proved elusive. The reason perhaps is that each was too radical and innovative to be transitioned and integrated into a conventional military or commercial "way of doing things." Scaled Composites is now owned by Northrop Grumman Corporation; it will be interesting to see if there can be a more successful transition or translation of Scaled's innovation into more traditional products. Interestingly, and perhaps not so coincidentally, Northrop Grumman also has a joint venture partnership with Applied Minds, where it deliberately uses the Applied Minds' innovative approach for early R&D, concept engineering, rapid prototyping – and in many cases, this prototyping results in actual products for customers.

The researchers believe a low-risk project is needed that both opponents and proponents of rapid will embrace. Crafting such an agreement will be the real challenge of the effort, not the execution of the program. The RT-34 vision of how to accomplish this is to give each camp what they need to support the effort. The proponent's position of rapid is both easy to understand and obvious. If a significant rapid program can be implemented, their careers, claims and aspirations will be validated. Bringing along the opponents (acquisition traditionalists) is where the struggle will be.

The opponents must be convinced by the following argument. From their point of view, a modest amount of money will be wasted, but if it doesn't come out of a particular budget they control, it may not matter to them. The money must be "someone else's problem" and so also must be the failure, for they will be sure of the rapid project's likelihood of failure – if not in execution, or in demo of operational use, then in transition into a program of record. This certainty of failure is the "judo" by which a rapid program can win in the face of overwhelming odds.

Since the opponents are convinced of the certainty of failure and the unwillingness to take on what they perceive as too much risk, they can be convinced into supporting the effort because they will believe that an ignominious failure will once and for all time discredit the concept of rapid acquisition. Once discredited, they won't have to further face the threat from rapid programs over the balance of their careers. This certainty will be the undoing of the conventional program approach, but only if rapid can deliver. If the rapid program cannot deliver, then this may be a blow to the rapid approach, but in the RT-34 view, it is a risk worthy of being taken. The "bet" on program selection is laid out in illustration Figure 5-3.

Note that the assumption of absolute success or failure of one approach or the other does not take into account the "experiential development" that takes place during a rapid acquisition program. Rapid programs can be used for the purpose of giving personnel (especially junior personnel) a suite of experiences during an entire acquisition cycle. This concept is described in the next section.
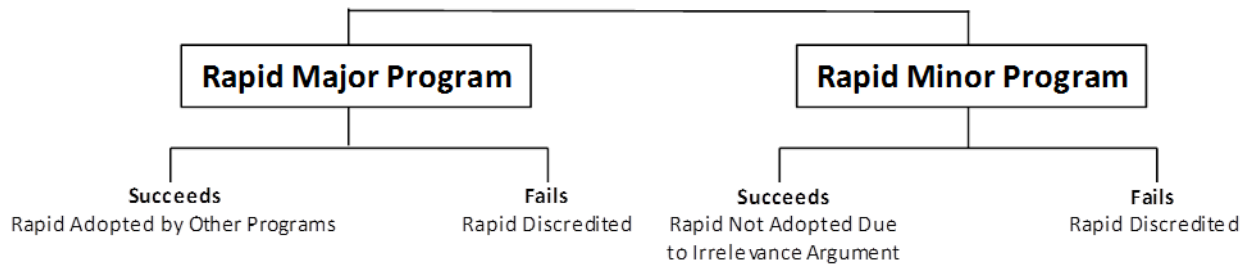
Figure 5-3: Relevant vs Irrelevant RT-34 Phase 4 Demonstration

If this outcome is accepted as the likely outcome, then the next question, and arguably the only significant question, is what program could be infiltrated using the rapid SE framework?

5.2.3 PROGRAM RECOMMENDATION – GPS

Choice of the program to validate is an acutely important consideration. If a stand-alone program is proposed, the risk is that there won't be sufficient Congressional or DoD support for the program itself, and it will be stillborn or canceled at the first opportunity. If the program is warfighter critical, the argument can be made that a rapid demonstration is unethical, since it would put troops lives at risk. This is a high barrier to overcome. The research therefore needs to look for an existing program where conducting a rapid demonstration would have minimal or no effect on a critical DoD function, but one where a rapid demonstration would have a high impact on the perceptions of decision makers and increase the odds of further support. This seemingly incompatible pair of requirements presents a conundrum. The Global Positioning System (GPS) may be a good solution – it is a ready-made, incremental, highly valuable and publicly visible program of record to host a demonstration.

The GPS program has the perfect combination of program attributes to demonstrate the impact of low risk "rapid." It is incremental, with spacecraft replacement happening on an episodic basic over decades. It is highly visible: everyone has GPS on their phones, in their cars, or on their aircraft, ground vehicle and ship. The public has all have seen the precision of GPS-guided ordnance in action (recall CNN showing the details of bombing enemy targets in Afghanistan and Iraq). If a rapid alternative spacecraft could be introduced into the GPS constellation, and built/operated for 10-25% of the cost of current spacecraft while providing 80-100% of the current capability with minimal technical debt, this would be a winner. If it doesn't work, there is no threat to the GPS mission.

Another good reason to use GPS is there already is an existence proof of being able to build a low cost spacecraft that can be part of a GPS constellation. This is the European Galileo precursor spacecraft built by Surrey Satellite Technology Ltd for the European Space Agency's "alternative to GPS" program. SSTL originated in an academic/research environment at the University of Surrey, then became a separate company, and now is an independent British company within the EADS Astrium NV group. SSTL is the leading provider of rapid small spacecraft and has a track record of delivering successful small satellite missions for over 25 years. What Surrey has already accomplished with Galileo can likely be replicated quickly and extended by a U.S smallsat builder, perhaps with a smart teaming arrangement.

An existence proof provides the high cover needed to prevent overt skepticism that a demo would be a "one time wonder" that is too innovative or too "radical" to be used in operations. At the same time, as part of an incremental approach, it would not challenge existing organizations that it might actually be intended to "go operational". Once the capabilities of the system become highly visible, existing organizations may even become more enthusiastic and start supporting exploration of options for "rapid transition to operations." Just as early

design engineering decisions determine the costs of expediting, early trade analysis of a successful demo system being used in operations becomes itself an existence proof and platform for exploring the possibility of pre-planning a transition.

If a rapid GPS demonstration is successful, it could alter the entire landscape of DoD procurement and open up the possibility that systems engineering will evolve naturally out of its current state to become more innovative and responsive. The process will iterate. Career opportunities will develop to "pull change up the chain". The need for the right people, in the right place at the right time will require systems engineers to evolve from "SE Bookkeepers" intent on checking off boxes and maintaining accountability, into "SE CFOs" capable of engineering leadership, flexibility, strategic decision making and organizational savvy.

5.3 PROPOSED FUTURE RESEARCH

The RT-34 researchers have identified a number of additional research questions and areas of proposed research. The team recommends that these research areas be explored prior to or in conjunction with implementation of the RT-34 framework on a DoD acquisition program.

5.3.1 LANES OF ACQUISITION – HOW DOES THE FRAMEWORK APPLY?

The major finding of Group 2 was that there was not a single rapid, but many different flexible rapids. This was based on observations of multiple lanes of acquisition, depending on the people, product, and process context of the rapid development activity. Lanes of DoD Acquisition found in the RT-34 research may relate to new acquisition lanes under consideration for updated DOD 5000. [Kendall, NDIA 2012.] This raises new research questions: how do the principles and attributes from rapid development apply to different domains and different lanes of acquisition. And do they apply equally? Additional research can be conducted to examine the principles and attributes observed in each of the framework levels and then correlate them to the lanes of acquisition.

5.3.2 WORKFORCE DEVELOPMENT: USE RAPID PROGRAMS AS TRAINING EXPERIENCE FOR JUNIOR PERSONNEL

Experiential development (training) was a recommendation from this study – i.e., Training in Lean Product Development, training in Agile system and software engineering, and training/ awareness on flexibilities inherent in hiring and contracting practices. This effort would baseline the current workforce knowledge, skills and abilities in rapid principles and aim to develop a workforce development strategy. The training could take several forms.

Using Rapid Acquisition Programs as an "Experiences Developer"

Personnel (from engineers to program managers to contracting officers) who participate in a rapid program see a full lifecycle of acquisition from problem statement (e.g., from the warfighter) to fielding (or maybe even disposal) in a very short time, say, two years. In the same two years in a traditional acquisition program, the personnel maybe see a portion of one milestone, with experiences that consist of powerpoint charts, budget development and justification, bureaucratic meetings, and seeking advice from support contractors. This contrasts with the depth and breadth of experiences that result from seeing a program from start to finish in a short time, with the urgency of the warfighter paramount. Thus, rapid programs can be used for the explicit purpose of developing experiences (with emphasis on the plurality of the word experiences) for the workforce in seeing an entire acquisition cycle and ultimately translating that knowledge into future programs and career development.

This concept emerged as a result of observations from site visits, anecdotes from socializing this idea, and the authors' personal views noting how much of their own experiences and career were influenced by working on

such programs and actually "seeing" all the elements of an acquisition cycle in a short time. Three specific examples were seen in the site visits.

- Organization A. This program contains a myriad of rapid programs within it (and has been doing so for many years). This organization is a "self-contained rapid ecosystem" that includes everything from design to internal contracting. People inside of this system experience a full lifecycle of acquisition, from the warfighter expressing a need to examining the full realm of capabilities, to executing on the program and bringing it to fruition and getting the capability into the hands of the warfighter.

- Organization B. This organization realized that it kept going to the same 5 people (by name) when it needed something done quickly. This was not sustainable, and the organization needed a way to replicate the "attributes" that these 5 people represented. So it created rapid component development programs, on the order of 18 months, to cycle people through as part of a career rotation. This served the purpose of gaining experience on a program from design to testing, created more people with more skills that could be used on other longer and bigger programs, and also enabled the organization to develop more components that had opportunities to be used in future applications, especially those that emerged rapidly. This approach is very similar to rotational "leadership development programs" seen in industry. As a result, they no longer to go the same 5 by name, but rather have a team of individuals to go to by attribute.

- Organization C. Organization C also is focused on quickly getting capability into the hands of the warfighter faster. This organization hand-picked SMEs to lead key elements of the organization who had a career of experiences that enabled them to know how and when to tailor and scale, to understand risks, and to work the system to get things done. They served as examples for other members of the team, who had less experience or different experience. This organization also experimented with a different approach to mission assurance, in which SMEs were embedded in the organization to manage risks in parallel. This required a certain level of experiences and trust to succeed.

- University Analogs for Senior Design Classes. The SERC has also seen senior design projects (such as those examined in RT-19 Capstone) and the researchers are familiar with programs at universities to quickly design, develop, and fly hardware such as UAVs or small satellites. Small satellites, for example, originated out of the university environment, with Stanford leading in the US and Surrey leading in the UK. Now, small satellite design courses are popular throughout the major aerospace engineering schools both at the undergraduate and graduate level. For example, AFIT's senior design program creates, tests, verifies, and even flies small satellites.   While some traditional programs may consider small sats to be "toys" and not useful for big satellite programs, the reality is that this platform gives a full systems engineering cycle (and specialty domains) that can rapidly develop and test technologies in a low-cost, low-risk environment that can be applied to future programs. Many universities are also using UAVs for the same purpose in senior design classes – these are even easier than small satellites because they can be "flown" outside very quickly and not wait for a launch vehicle. While these analogs give a good perspective on expedited systems engineering, they do not necessarily address the context of an acquisition system and the dynamics of working with rapid contracting, running program management meetings, etc.

So what do and did people learn from these examples? They experience a compressed version of program management, systems engineering, contracting, effects of decision making, importance of communication, how to build and be part of a team, how to make mistakes and learn from them, importance of listening to the user (warfighter) and translating those needs into capability, managing a budget, etc. In all cases, junior personnel would be placed side by side with experienced personnel. These experiences are valuable at any point in one's career, but the point would be to see these experiences earlier, so that once an engineer, program manager, or

contracting officer goes to a traditional program, they have a perspective of what it means to get things done and how to actually do that. This has the potential of transforming the way the government manages programs. While an expedited development process can provide a deep educational experience for those who are involved in it, its effectiveness can be enhanced by suitable orientation for the participants to help inform them on what to expect and how to best take advantage of the opportunities present in this environment. Individuals need this exposure, and at the same time, it is critical that teams learn how to work together in an expedited environment.

One means of providing this individual and team training is through the use of simulations and team building exercises and conducting this in conjunction with (before, during, after) the hands-on experience.   For example, the SERC Experience Accelerator (SERC RT-16) is being developed to provide an open source environment to support such an individual and team building environment.   The Experience Accelerator is being designed to facilitate the development of experiences customized to particular domains to allow individuals and teams to experience an entire system life cycle in a matter of hours rather than years. The objective of the simulation is to provide a safe, yet authentic environment in which participants can make mistakes without adversely affecting their careers or programs.   The simulation provides the participants with the ability to view a program through the entire lifecycle, see the relationships between elements of the system, and the system developing the system and encounter the challenges faced in an expedited system development. One of the critical aspects of the simulation is to ensure that the participants are able to navigate through the "gray" zone and create mental templates that can be applied to similar future situations. All of these are required to provide experience acceleration that can be used to prepare individuals and teams for an expedited system environment. The Experience Accelerator could be a companion to the rapid development rotation cycle.

<u>Incorporating Framework Elements into Workforce Development and Training Programs</u>

Other focused "training" programs can be developed that provide insight to and increase awareness of the elements of the framework. The training can start from Level 1, with basic best business practices, and expand to including tutorials on flexible contracting methods, exploring all the contracting tools and mechanisms available to contracting officers, but with which only a specialized few have knowledge, experience, and confidence in implementing. Mentoring and knowledge transfer can also be incorporated into the training. These programs would go a long way to building the cultural transformations needed for Level 2.

Hypothesis: The Expedited SE framework is a function of rapid programs. However, applying the framework to traditional programs does not necessarily result in those programs going more rapid. The "secret sauce" to rapid consists of the people and team with a set of prioritized attributes that enable the go fast culture. The secret sauce can be captured through experiential development of the workforce that exposes them to scenarios in which to gain the attributes necessary. Several organizations (both rapid and traditional) have developmental programs that can be used as models for incubating the workforce with these attributes.

Proposed (Draft) Approach
1. Identify how rapid organizations achieve the Expedited SE Framework concepts; identify/ refine any missing attributes, especially regarding culture and team, with the RT-34 SMEs. Discuss priorities of these attributes.
- Identify "hybrid" programs (such ISPAN at Hanscom AFB) that appear to use the same attributes as the Expedited SE Framework, but are considered "traditional" acquisition programs constrained predominantly by DOD 5000.
- Assess attributes in the hybrid programs and compare/contrast to the rapid ones.
2. Identify "incubator" opportunities used by the RT-34 organizations or newly identified hybrid organizations as a template for experiential workforce development. For example US SOCOM's Research Development Acquisition Center (SORDAC) has a "ghost program" where young officer rotate through a SORDAC project, then deploy to serve as a liaison officer between ops and acquisition.   Similarly, US SOCOM creates Distributed Cells (Junior engineers at various acquisition, research and test organizations) that cooperatively acquire rapid solutions under

SORDAC leadership. Another example was NASA Goddard's rapid instrument program and focus on hands-on activities (OJT) early in junior employee careers.

- This activity would document the objectives of these programs, metrics, capture scenarios, and numbers; it would capture lessons learned and challenges. It would seek to discuss the experience with selectees/ graduates, and capture their follow-on and previous assignments. This phase would determine the impact of their rapid acquisition experience on their career path and choice. Integrate these findings (recommendations) with existing assignment, promotion and career shaping processes.

3. The results, together with the development of rapid acquisition scenarios, can be inserted into the "open source" RT-16 Experience Accelerator and used to develop a module for academic course content. This task could also include student assessments at various SERC member institutions.

5.3.3 FURTHER ITERATION AND VALIDATION OF THE SE EXPEDITED FRAMEWORK, V1.0

The framework iterated at least four times during the course of research as data were analyzed and feedback received. The research would benefit from a "Round 2" set of site visits. The RT-34 site visits were conducted with headquarter level organizations (not specific projects). The responses from headquarter level people could have been biased toward the overall context of rapid development and acquisition. Gathering detailed data on specific projects from site visits would further validate and refine the current Framework. In particular, this could help delve deeper into the systems engineering aspects of the projects by those individuals who are focusing on that level of work.

A. Project Level Case Studies. Many of the interviews focused at the SME and senior levels of the organizations. A follow-on study should relook these observations, finding and recommendation by interviewing project level management and engineering staff. Using the case study method, the research collect specific information on the current set questions, but also on specific project data.

B. Check Framework Hierarchy. Future research could continue to iterate on the framework and the practices identified within each level of the framework. For example, interviewees could be asked what are the practices they believe are the "best ones," and if they followed the practices, in what order would they implement the practices. This would provide data that would indicate whether the framework is hierarchical.

C. Examining Success and Failure. RT-34 began with an assumption that the framework would guide a set of critical success factors. It became apparent during the data analysis that the questions assumed a level of success, but the questioning did not specifically ask whether certain practices absolutely resulted in success (or failure), and what were the criteria for defining success or failure. Now that the framework is developed as a result of the interviews, questions can be asked as to whether the framework elements are indeed contributors to success or failure, and if so, to what extent. As a result, one recommendation for follow-on research is a more structured approach with specific questions to assess the use of the framework, as well as its contribution to the success or failure of a project as defined by the organization. In particular, one should try to ascertain whether the provided framework is sufficient to ensure a successful project, or whether it is merely necessary to ensure a project does not fail outright. These new questions should be used to re-interview the interviewees at a program or project level in order to assess the frame work in specific environments. The new questions can also be used to interview other programs, including traditional, to assess how the framework applies outside of the rapid world. The results would validate the framework, or perhaps result in another round of iteration on the framework.

D. "Lanes of Acquisition" Analysis and Tipping Points. Future research will also need to be done to determine the relationships between the principles, program lanes, expedited capabilities and degrees of success. This work is critical to determine which programs are suitable for expedition, to set expectations

appropriately, and to determine which techniques and tools should be utilized for the program. Research is needed both to gather the necessary information through surveys and the mining of existing information, performing the necessary analysis to define the qualitative and quantitative relationships, and finally, creating the tools which enable practitioners to effectively use this information.

A related concept offered by the AF Center for Systems Engineering was a concept of a "tipping point." Assuming the lanes of acquisition are correlated to rigor of systems engineering, what program characteristics "tip" a program into a different lane. This tipping may then require a program to backtrack in the lifecycle to redo (or do) various Systems Engineering task.

E. Framework Validation. During any implementation of the framework (Section 6.2), longitudinal studies should be conducted during the project's lifecycle.   This would be research to shadow a rapid program, either one already in development, or one proposed herein. This would allow real-time gathering of data to refine the framework and capture best practices.

5.3.4 RESEARCH IN INTEGRATION OF CRITICAL FACTORS ACROSS THE SE EXPEDITED FRAMEWORK

While there are many methods of expediting programs, as shown in Chapter 2, each supporting one or several other Observations, they are all dependent on critical aspects of the program, the system characteristics and environment in which it is being developed and used, and the capabilities of the organization and team responsible for the system.   This proposed research would examine these relationships, exemplified in the Equation in Figure 5-4, as a predictive/ assessment tool.

Results = [SuccessMetrics X Mission/SystemType] X [OrgCapabilities X Techniques]

Acquisition Lane   Expedited Capabilities

Figure 5-4: Predictive/Assessment Tool

Without the appropriate environment in each of these areas, many of the reported methods for program expedition will be compromised and may even cause more delay to the development and deployment of the system. Therefore, it is necessary to characterize this information to allow those developing organizational and program processes to determine an appropriate set of techniques to expedite (or not) a particular program.   The following is a definition of each of these characteristics:

Success Metrics **–** This defines the objectives for the program and what it is attempting to achieve. In some respects, this defines the lanes if you will where changing some of these characteristics could result in the need for very different expedited expectations and approaches.

The following are a set of high-level success metrics that can be used to characterize the desired outcome for a system:

*   **Schedule:** The amount of time required from commitment to begin program until it is providing the desired benefits in the field.
*   **Cost-Effectiveness:** systems that need to be designed to be of minimal cost often take substantially longer to optimize and produce.   This may relate to the R&D cost and/or cost of the system over its lifecycle.
*   **Capability:** If this system is being designed to replace an existing system of similar capability, it is likely that it will be less possible to trade off features for schedule. Flexibility is a very important aspect to allow for changes in the capabilities during the entire lifecycle from development through deployment.   In any case, it is likely that there will be a set of features that are critical to its success.

- **Scale & Duration of Deployment:** The number of systems being deployed and duration of deployment impacts the need for a robust supply systems that need to be widely deployed over long periods of time, often require far greater amounts of planning and engineering for success.
- **Accountability:** The degree to which costs and effort need to be monitored and accounted for adds an increased burden and adds delay to the program, particularly when decisions need to be approved at high levels. (Assurance & Validation)

Mission/ System Type – this determines to a large degree the amount of work that needs to be done. It could be correlated with the COSYSMO/ CORADMO metrics to provide some measure of the likely duration of a project. A number of critical system factors are described in the "Balancing Agility and Discipline" by B. Boehm and R. Turner (2004), which determine the "home ground" for agile versus planned approaches, with the former often being identified as being the most expeditious. Some identified factors were:

- **Size:** small being most amenable to rapid techniques
- **Criticality:** non-critical designs requiring the least amount of pre-planning
- **Dynamism:** change is most challenging for planful approaches

Organization/Personnel Capability – these define the capabilities of the organization and may limit which techniques can be employed successfully. As noted in B. Boehm (2004), the capabilities of the organization are critical to the successful implementation of agile methods. The same is true for expediting programs as well. The following three factors include the two factors found in B. Boehm (2004) and with the addition of alignment of incentives with program objectives as noted below:

- **Human/tool capabilities:** (**Personnel):** it is noted that agile approaches require the continuous presence of a critical mass of scarce experts; this is especially true for expedited programs. It is believed in software development, that a topnotch programmer can do more than many mediocre ones and with much higher quality and far less supervision.
- **Trust (Culture):** agile development thrives in a culture "where people feel comfortable and empowered by having many degrees of freedom". The scope of trust is an important element for expeditious behavior and extends throughout the organizations in acquisition, development and deployment, and particularly in the interfaces between these three. As noted by P. Lencioni ("Five Dysfunctions of a Team") and others, Trust is the critical foundation of teamwork without which it is not possible to effectively team or collaborate.
- **Alignment of Incentives with Program Objectives (Governance):** Quite often the existing incentives are to prolong a program, rather than complete it as efficiently and effectively. Alignment must be in place at all levels to ensure that all of the capabilities are deployed effectively to achieve the desired outcomes.

5.3.5 RESEARCH BALANCING CAPABILITY, SCHEDULE, FLEXIBILITY, AND TECHNICAL DEBT

The ultimate goal of today's systems and systems of systems (SoS) is to provide capabilities to the stakeholders and users of the systems. These capabilities range from "must-haves" to "nice-to-haves", often with disagreements among the stakeholders and users as to where each capability lays in this spectrum. There are many choices in developing and evolving systems to provide these desired capabilities. These choices are typically related to development processes and product architecture decisions. Initial choices are often driven by business needs such as time to market, the desired level of performance of the capabilities, and available resources such as engineering expertise and funding. In addition, these choices often result in longer-term consequences that range from good (e.g., market share or future opportunities) to bad (e.g., missed market share, technical debt, or a

failure to provide the desired capability). Other times, no particular attention is paid to these choices—they happen without much forethought, but still with the resulting longer-term consequences.

Similar to the previous research proposal (Section 5.3.4), this proposed project studies the capability and affordability tradespace of expediting systems engineering to reduce schedule and cost, encouraging flexibility in architecture decisions to support future evolution of the system, and examining technical debt that either results in later rework or adversely impacts future options. In addition, this research would examine how pedigreed systems engineering cost models can be used in the analysis of this tradespace to show the range of options and the resulting consequences. While the previous proposal examined: 1) Success Metrics, 2) Mission/System Type and 3) Organizational (expedited) Capabilities, this research would examine those in addition to Flexibility and Technical Debt.

Proposed Tasks

This proposed effort will build upon three related SERC research tasks along with initial research on technical debt conducted by the Practical Software and Systems Measurement (PSSM) affiliates (http://www.psmsc.com/) to analyze actual project data that has been previously collected. The proposed research will strive to understand the limits of expediting engineering with various development approaches and develop new models based on the current COCOMO suite of cost models to determine reasonable balances between expediting engineering, valuing flexibility, and managing technical debt.

Data analysis could occur on several fronts:

- Existing project data to identify productivity rates and compare them the nominal cost model outputs.
- Cost model parameter analyses to quantitatively determine to potential influences of various development approaches, techniques and staffing with respect to expedited engineering, system flexibility, and technical debt for initial system development. Cost model parameter analyses to evaluate the influences of the various development approaches and architectures to system total ownership costs over time.

In addition, more recent SERC research reports and other literature will be mined for additional case studies and potential influence factors with respect to expediting systems engineering and schedule-driven development. The goal of these analyses is to refine the parameters and use the actual project data and COCOMO suite of cost models, illustrated in Table 5-1, to determine effort and schedule benchmarks for the various system domains represented in the data sets. In addition, these analyses will be used to develop a composite model to investigate the expediting engineering – valuing flexibility trade space. This composite model will pull from the COCOMO suite of cost models plus the total ownership cost model developed for the SERC Valuing Flexibility research task (Boehm, Lane & Madachy, 2011).

The composite model developed for this research effort will be used to better understand the optimal ranges for both expediting engineering and valuing flexibility with respect to system development schedule, total ownership costs, and technical debt. To do this, the COCOMO model parameter values will be used to evaluate the SRDR, COCOMO, COSYSMO, and student project data to understand the relative level of expedited engineering associated with each project. The actual project data will also be used to establish schedule benchmarks for the various system domains for which data is available. This information will be used to develop a new composite model that will show the limits of expedited engineering with respect to total ownership costs and technical debt for various expedited engineering approaches.

Table 5-1: COCOMO Cost Models

Cost Model	Description
COCOMO II (Boehm et al, 2000)	Constructive Cost Model for software
COQUALMO (Boehm et al, 2000)	Constructive Quality Model
COPLIMO (Boehm, Lane & Koolmanojwong, 2010)	Constructive Product Line Investment Model
COPSEMO (Boehm et al, 2000)	Constructive Phased Schedule & Effort Model
CORADMO (Boehm et al, 2000)	Constructive Rapid Application Development Model
COPROMO (Boehm et al, 2000)	Constructive Productivity-Improvement Model
COCOTS (Boehm et al, 2000)	Constructive Commercial-Off-The-Shelf Cost Model
COSYSMO (Valerdi, 2005)	Constructive Systems Engineering Cost Model
COSYSMO for SoS (Lane, 2009)	Constructive System Engineering Cost Model for SoS Engineering

5.3.6 EXPEDITED WORK ANALYSIS

Given the 11 Direct Responses, the research team then put these observations in the context of transformations (functions/ tasks) needed across the lifecycle. By examining the generic development process, especially for lean development, the transformations build a task network can be analyzed for stall, waste, missing value, lack of improvement, quality/ redo, etc. This analysis of the task network is another follow-on research proposal.

These are typical lean development principles. Generally, core lean activities include:

Specify value: Value is defined by customer in terms of specific products and services, but could include sustainability or reliability of the solution, integration with other systems (System of Systems), and for this report - schedule. JUONS need to be satisfied quickly to reduce risk of harm or loss of life.

Value stream mapping: Map out all end-to-end linked tasks, activities, and processes necessary for transforming inputs to outputs to identify and eliminate waste.

Make value flow continuously: Having eliminated waste, make remaining value-creating steps "flow". This can be considered having the lifecycle product iterate.

Customers pull value: Customer's "pull" cascades all the way back to the lowest level supplier, enabling just-in-time production

Pursue Perfection: Pursue continuous process of improvement striving for perfection

One engineer called lean development principles "the focused application of common sense". Although based on simple concepts, the complexity arises in having many people adopt and implement the ideas, often needing to "retrain" project personnel. *Lean thinking* is the dynamic, knowledge-driven, and customer-focused process through which all people in a defined enterprise continuously eliminate waste and create value (Murmun et al, 2002). More recent findings (Oehmen, 2012) have taken these lean enablers/ activities and added one additional - respect for your people. With this background on lean processes, we examined removal of work/ waste from the lifecycle.

5.3.6.1 Project Life-Cycle Transformations

The major objective of rapid projects is to reduce the latency from start to an effectively deployed system that meets the warfighter's urgent need. The process of creation from start to deployment is one of transformation; be it the transformation of opportunity, to concept, to design, to finished good and finally to deployed utilization. Necessary for this success is an understanding of the context of the system and the potential value creation space. To reduce latency, the analysis and assessment of this space should be an ongoing process. For this discussion, we will assume that this work occurs outside of the conceptualization to deployment process.

Once the system context and value creation space is understood, the next set of transformations is the creation of a concept that provides the desired value in the aforementioned context. In a planned process, this can involve a detailed stakeholder interview and requirements solicitation process, resulting in a concept of operations and subsequent requirements. In a lightweight process, this could involve an intense iterative interaction between the stakeholders with the result being the creation of a set of models, or other multi-model artifacts that can be used directly in the subsequent stages of the process.

The following set of transformations is the architecture, design and development of the actual system (product, service, etc.). The various levels of abstraction required depend on the scale and complexity of the actual system that is being implemented. For heavyweight DoD processes, there are a number of documents that are contractually required. For lightweight operations, the documentation might be the system itself, and perhaps a suite of tests, with additional embedded comments. The final transformation is that of transitioning the system into actual use. This involves making the system available to the users and providing the necessary training and support. Lastly, closing the loop is the evaluation of the efficacy of the system which feedbacks into the context analysis and assessment which will facilitate the creation of future system's concepts.

A framework for these transformations is shown in Figure 5-5 (Wade et al, 2010).

- **Value -** This includes understanding an environmental context, understanding factors that influence the creation of value, and discerning how value may be created within it. To be successful, the decision maker should understand the total value proposition which includes customer needs, not just customer "wants", and how satisfying them brings value to the organization.
- **Conceive -** This includes the creation of a conceptual or abstract design that creates value. Architects, stakeholders and particularly user representatives may be involved in this activity.
- **Develop -** This includes the design, manufacture and whatever else is necessary before the system can be used. This activity usually includes engineering and manufacturing.
- **Use -** This includes the distribution, deployment, use, maintenance, and eventually retirement of the system. This activity includes sales and service and, of course, the end user.
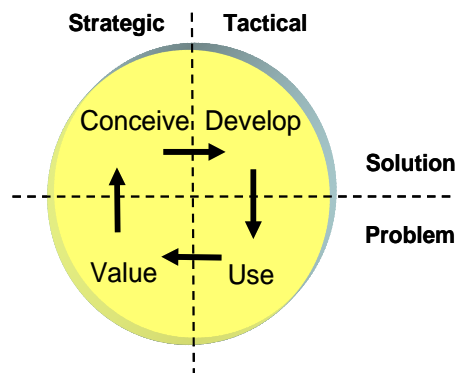
Figure 5-5: System Life Cycle Activities

5.3.6.2 Life-Cycle Latency Reduction Techniques

Given this set of necessary transformation, how can the lifecycle process be expedited?   One can think of these transformations in computing terms in which many of the same latency reduction techniques can be used.   Below are six classes of techniques that can be used to reduce latency as shown in Table 5-2. These techniques reduce the total amount of work (total, new and unanticipated), increase efficiency, and increase throughput and/or decrease stall time. They are described below.

Table 5-2: Program Expedition Techniques

Area	Techniques	Impact
Product	1. System Simplification	Reduces total work
	2. Legacy Reuse	Reduces total new work
Processes	3. Transformational Efficiency	Increases efficiency
	4. Rework Avoidance	Reduces rework
People	5. Parallelization & Performance	Increases throughput
	6. Improved Decision Making	Reduces "stall" time

These latency reduction approaches can be visualized by studying the systems engineering process as a task network. Figure 5-6 shows the network of system development tasks with backtracking and decision gates. While this model is a bit oversimplified, given that the real world has partial dependencies and more complex constraints, one can still use such a model to identify sources of calendar time reduction.

Figure 5-6: Systems Engineering Activity Network with Backtracking
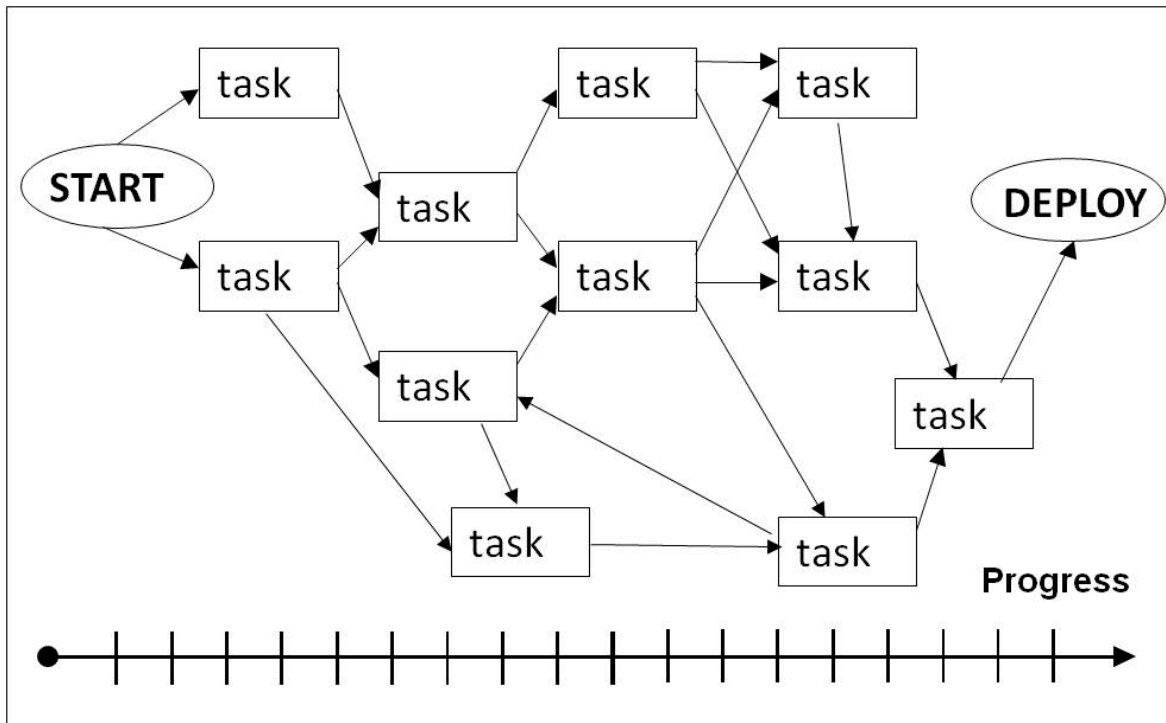
1. Product or System Simplification

The most important means of expediting a program is to reduce the amount of work that needs to be accomplished by keeping the concept and design as simple as possible. Usually, this involves simplifying how the system is supposed to behave in the corner cases of operation. Error systems tend to represent a good deal of the complexity of systems, which is a great lever point for system simplification and work reduction. This also usually requires tradeoffs between requirements and system complexity as quite often a few sets of requirements can drive system complexity and project schedule well beyond what they are individually worth. Success usually requires some form of crisis for these difficult tradeoffs to be made as it is usually at this stage of a program that is it being "sold" to the many stakeholders and there is a great deal of requirements creep.   For the tradeoffs to be effective, the technical assessment team needs to be composed of people who are experienced in this type of program design, have worked together in the past which builds trust, are free to communicate openly and honestly, and have credibility in the organization. This enables trades to be made quickly and equitably across the system space.

2. Legacy Reuse

Another means of reducing latency, but not necessary overall work, is to do as much of the work upfront before the project initiation as possible. This is broadly applied to all forms of legacy including concepts, documents, designs, components, subsystems, training, etc. This is where the concepts of product lines, modular libraries, patterns, and standard interfaces come into play.   Depending on the amount of intellectual property reuse, supporting this could actually require more effort at least initially, but the impact could be to greatly reduce latency from start to deployment. A representative product line approach achieving a factor-of-4 decrease in development time is shown in Figure 5-7.
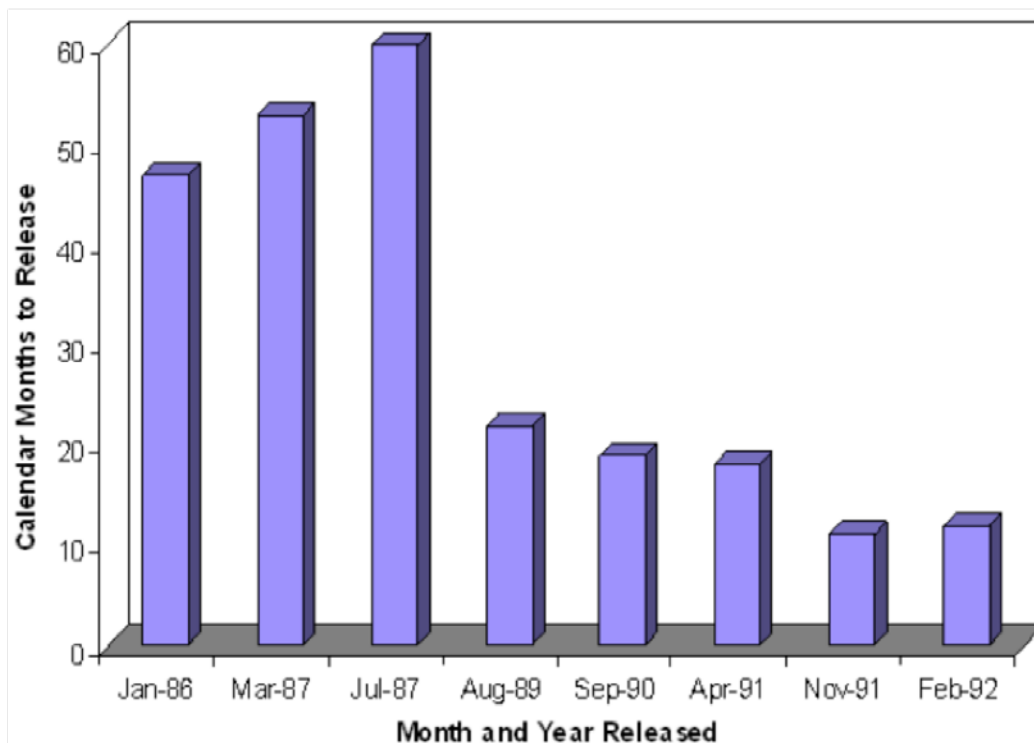
Figure 5-7: HP Product Line Reuse Investment and Payoff

In the late 1980s, Hewlett Packard (HP) found that several of its market sectors had product lifetimes of about 2.75 years, while its waterfall process was taking 4 years for software development. HP's investment in a product line architecture and reusable components increased development time for the first two products in 1986-87, but had reduced development time to one year by 1991-92 (Lim 1998). Similar Platform Based Engineering initiatives in DoD hardware and software domains can have similar payoffs in time to first article development.

Reusing systems engineering assets, model-based systems engineering (MBSE) capabilities, and automated SE artifact generation have been shown in the COSYSMO 2.0 systems engineering effort estimation model (Fortune, 2009) to eliminate significant sources of SE effort. For example, the COSYSMO 2.0 reuse-related percentages determined by a combination of expert judgment and data analysis are an added 38% effort to design SE artifacts for reuse, and a savings of 35% for reuse with modification, 57% for reuse without modification but a need for testing, and 85% for reuse without modification or testing. Not all of this saved effort will be on the critical path, but much of it will be. However reuse will require up-front investment in domain engineering and structuring SE artifacts for reuse. A more detailed discussion of COSYSMO and other tools is in Appendix D.

A further quantitative model for estimating schedule acceleration was developed, based on integrating the schedule predictors in the previous CORADMO model with the product, process, people, and project factors identified in the RT-34 research. The effect of these factors on project duration was calibrated to a database of 12 agile software projects from the AgileTek Company. The projects ranged in size from 10 KSLOC (thousands of source lines of code) to 409 KSLOC, and had sufficient schedule driver data to enable a calibrated set of parameters to be derived that enabled estimation of eleven of the 12 projects within 16%, with one explainable outlier off by 53%. The resulting model was able to explain the results of an initiative by a different corporation that failed in its initial attempt to transition from a plan-driven to an agile development, but that used insights from the initial attempt to achieve a successful schedule acceleration in its second attempt. The model, calibration, and case study are presented in Appendix E. Further research is proposed to gather additional data and to calibrate the model to a broader range of projects and organizations.

3. Transformational Efficiency

Another means to reduce the overall workload is to reduce the amount of work that needs to be done in these transformations. Given the scale and complexity of the system, the number of internal abstractions of these transformational representations needs to be minimized. This reduces the amount of time that it takes to produce these, but more importantly reduces the serialization effects of having changes ripple through all of these. One could argue that the least number of transformations would be to create a concept that is embedded in a set of interaction models which is updated to include the actual design, and then is used for deployment and training. In this case, very little additional intermediate design representations and documentation may be necessary.

Business process re-engineering or lean thinking (Womack-Jones, 2003) can discover and eliminate non value-adding tasks, such as unnecessary coordination cycles, purchase approval signatures, or change control boards operating at too low a level.

Reducing time per task can be addressed through technology or management. Tools, models, and automation can accelerate SE tasks, as highlighted in the ODDR&E Rapid Capability Fielding Tools Study (Carlini et al., 2010). SE acceleration tools identified in the study included visual modeling, rapid prototyping, modeling and simulation, model-based artifact generation, architecture-based attribute and tradeoff analysis, and integrated SE environments with tool interoperability. Some good earlier sources for reducing time per task in the software area are (Arthur, 1992) and (McConnell, 1996).

4. Rework Avoidance

In traditional "Vee" based SE processes, verification and validation happen near the back end of the process. Unfortunately, this means that any detected issues are found late and may have a significant impact on the time necessary to deliver a functional system or product.   The time necessary to wring out the last remaining issues in a system or product can sometimes is the dominant factor in schedule delay.   Quite often, expedited programs use a continual verification and validation methodology that can significantly reduce the impact and cost of detected defects.   In this way, issues are detected and resolved as early as possible reducing the amount and negative impact of rework.

Rework is perhaps the most common form of time-sink that system development projects experience. Generally, rework does not add value. Thus, a major challenge and opportunity involves minimizing its occurrence and impact. Early and continuous SE verification and validation (V&V) via automated analysis tools, modeling and simulation, prototyping, and independent reviews catch SE defects earlier when they are easier and quicker to fix. Evidence-based decision milestones provide a management framework both to synchronize and stabilize concurrent SE effort and to generate and review the evidence that the proposed SE solutions will enable satisfaction of the requirements within the budgets and schedules of the plan. Shortfalls in evidence translate into uncertainties and risks, which frequently translate into costly and time-consuming defects.

Investments in process maturity have been shown to reduce the incidence and negative impact of defects (Goldenson-Gibson, 2003). The CMMI process areas of "Validation, Verification" emphasize early defect identification and removal; and "Causal Analysis and Resolution" emphasizes root cause analysis to reduce future sources of defects. Finally, rework can be reduced by tightening convergence loops or by articulating where progress disconnects occur. For example, using collocation and virtual collaboration technology can reduce or surface misunderstandings among SEs, system stakeholders, and independent reviewers, and can avoid bad fixes through interactive discussions.

Evolutionary definition avoids definition of details best left to downstream increments, such as the details of decision aids for complex command and control systems. However, it is important to devote early effort to ensuring that the system's architecture will accommodate anticipated sources of system change and growth, thus avoiding easiest-first "mashup" early increments that foreclose options for growth and build up technical debt (Boehm-Bhuta, 2008).

5. Parallelization and Performance

Another means of reducing latency is to parallelize the work as much as is effectively possible until the point where communication overhead starts to outweigh the advantages of the distributed work load.   In this way, the latency effects of serialized efforts can be minimized. However, over-parallelization can create communication and decision making issues; e.g., the mythical man month (Brooks, 1995) comes to play here. Also, the effectiveness of the resources doing the transformation can be increased. This may be achieved by using more experienced and capable staff and providing them with all the resources that they need to accomplish the job.

On the management side, Pareto 80-20 analysis can be effective for work streamlining. For example, if 20% of the tasks cause 80% of the time delays, then task streamlining should be focused onto that 20% (e.g., defining and designing for critical off-nominal scenarios). Particularly for systems of systems, one way to increase effective parallelism in developing a number of components is to ensure precise, well-validated component interface specifications in advance of detailed component design. Then, the design and development effort for each component can proceed in parallel with minimal delays due to interface reconciliation or cross-component ripple effects. Often, management will try to save time by bringing the contributing-system providers aboard quickly without such interface specifications, but quantitative analyses have shown that such savings are eventually much

more than wiped out by late rework (Boehm et al., 2004). As displayed in Figure 5-4, project activity networks may reveal many possible paths to project completion. PERT/CPM tools and techniques may help identify critical paths in workflow, resource dependency, or schedule. When activity networks get too "bushy" (i.e., when certain activities have a high fan-in of input paths or fan-out of output paths), then bottlenecks can occur.

For example, many early project review procedures require mixes of SE artifacts and numerous other derivative artifacts such as plans for system installation, data migration, training, cutover, maintenance, operations, and support to come together at a single formal review. This frequently requires SEs to spend much of their critical path time in tutorial discussions of the emerging system architecture, when they need to focus on getting the architecture ready. It is better to schedule less-formal SE technical reviews in advance of the large, many-artifact formal reviews. Some early work on the derivative artifacts can be done in advance, providing useful context for the SEs, but the main work on the derivative artifacts can then be done once based on a well-vetted architecture.

Some other ways to get time-consuming tasks off the critical path include task decomposition and parallelization, or through network reconfiguration. Examples include pre-positioning of facilities, components, tools, experts, or data, which may add somewhat to the cost but be worth it in schedule savings. A good example is "overinvestment" in reusable components as discussed in *Eliminating Tasks*.

System development projects are sometimes prone to single point failures, which can negatively impact completion schedules. For example, SE support environments can go down or fail at untimely moments (a.k.a., "Murphy's Law"). Similarly, key project personnel such as lead system architects may leave the company or be pulled off to save another project. The basic way to reduce the risk of single point failures is to reduce both the probability of failure (e.g., by providing bonuses for staying with the project through completion) and the impact of failure (e.g., by spreading knowledge via task-sharing and peer reviews). The amount of risk exposure (Probability of failure times Impact of failure) is a good way to prioritize failure risk-avoidance efforts such as reducing the effects of personnel turnover.

Clearly, every project would like its SE team and its Integrated Product Teams (IPTs) of stakeholders to consist of the best people possible. Often, though, "best" is interpreted as "technically strongest," which often leads to continuing arguments among polarized experts and slow progress. An excellent set of criteria for "best" SE and IPT team members is provided in Air Force Instruction 63-123, Evolutionary Acquisition for C2 Systems (AirForce, 2000):

- *empowered* – have the authority to negotiate for the organizations that they represent;
- *committed* – provide continuous representation of their constituencies and ensure performance of actions necessary to achieving group objectives;
- *representative* – represent their entire constituency, not just a part or their personal positions;
- *knowledgeable* – be sufficiently aware of group objectives and have organizational, technical, and management expertise to ensure informed and effective collaboration; and
- *collaborative* – operate as team players and work toward win-win solutions for all stakeholders.

As discussed under *Avoiding single-point task failures*, a critical success factor involves establishing incentives to attract and retain the best SE and IPT team members. These can include bonuses for staying with the project through completion, (e.g. for evolutionary development, one does not dismiss the SEs after the first PDR), recognition of their key contributions, and SE career path progression.

A true CMMI Level 5 SE organization has accomplished the transition to a learning organization via the "Organizational Innovation and Deployment" process area. Learning organizations can do more than optimize and manage their processes. They have instead cultivated a culture of continuous improvement and process redesign as routine activities, rather than as uncommon events. They balance "skating to where the puck has

been" process improvement via root cause analysis and improvement over previous projects, with "skating to where the puck is going" efforts to anticipate, monitor, and prepare for future trends.

A good example is in applying trends in agile methods to SE. The key to agility in complex systems is for the participants to be able to operate via tacit interpersonal knowledge and interpersonal trust (Nonaka, 1991; Nonaka-vonKrogh, 2009), as compared to basing collaboration on explicit documented knowledge among participants unfamiliar with working with one another.   This implies both developing powerful virtual collaboration capabilities, and also involving the participants in realistic collaboration exercises that build up tacit knowledge, mutual understanding, and trust. Other good approach for transforming SE into a learning organization is contained in (Wade, 2010).

6. Improved Decision Making

One can think of these transformations in computing terms. Once you have reduced the amount of work, "pre-fetched" or pre-calculated as many results as possible, and have redistributed the computational load as much as possible (until the communication overhead starts to dominate); then all that remains to maximally reduce latency is to keep decision making off the critical path and the transformation process flowing smoothly through the system.   Perhaps the most effective means of doing this is to distribute decision making as much as possible and have it take place as close as possible to the point where the elements of the decision making are known.   A critical element to support distributed decision making is open, effective, low-latency communication. In addition, the concepts of Kanban can be applied where the transformation elements are pulled through the system keeping all transformational elements actively engaged in the process (which increases efficiency) and can reduce latency. One could think of this as a data flow model of computing or system creation.

5.3.6.3 Relation of Direct Responses to Life-Cycle Latency Reduction Techniques

The rapid development organizations emphasize, based on varying organizational or governance constraints, or lanes of acquisition, some set of people, process and product-related practices. These are the direct responses from the discussions with SMEs as described in Chapter 2.

- **Product:**
    1: Use Mature Technology & Reduce Complexity – Focus on State of the Possible (Reuse)
    2: Incremental Deployment (Development) is Part of the Product Plan

- **Process:**
    3: Strive toward a defined Set of Stable Requirements focused on Warfighter Needs
    4: Work to Exploit Maximum Flexibility Allowed
    5: Designing out All Risk Takes Forever…Accept Some Risk
    6: Keep an Eye on "Normalization"

- **People:**
    7: Build and Maintain Trust
    8: Populate Your Team with Specific Skills and Experience
    9: Maintain High Levels of Motivation and Expectations
    10: The Government Team Leads the Way
    11: Right-size the Program...Eliminate or Reduce Major Program Oversight

Each of these approaches has been mapped with the six different techniques as shown in Table 5-3. Note that a single method can expedite a program through a number of the aforementioned techniques.

Table 5-3: Expedition Methods

Area	Direct Responses from Site Visits	Expedition Methods					
		#1	#2	#3	#4	#5	#6
Product	1: Use Mature Technology		X				
	2: Incremental Deployment (Development)	X	X				
Process	3: Defined Set of Stable Requirements focused on Warfighter Needs				X		
	4: Work to Exploit Maximum Flexibility Allowed			X	X		X
	5: Designing out All Risk Takes Forever			X			
	6: Keep an Eye on "Normalization"				X		
People	7: Build and Maintain Trust					X	X
	8: Populate Your Team with Specific Skills and Experience					X	X
	9: Maintain High Levels of Motivation and Expectations					X	X
	10: The Government Team Leads the Way						X
	11: Right-sizing the Product …. Reduce bureaucratic oversight						X

5.4 SUMMARY

Two main research questions emerged that resonate with the sponsors:

- What are the principles and attributes that are seen in each level of framework and do they apply equally across all domains and all lanes of acquisition?
- How can human capital development improve by embedding acquisition personnel in programs to develop these principles and attributes?

Other questions arose after a peer-review "deep dive" of the RT-34 project. These questions included:

- Is there a depiction of the framework that is hierarchical in nature, such that it infers, and justifies, precedence or causality?
- How is DoD rapid acquisition different from DoD non-rapid or non-DoD rapid acquisition?
- How can a traditional acquisition (large ACAT 1) embrace appropriate factors of rapid organizations, effectively becoming a "hybrid" program?

The answers to these questions will be referred to any follow-on research. The SERC and the RT-34 researchers will work with the current and potential sponsors to agree on the follow-on research and the validation of the framework. This will also include identification of willing and able sponsors to provide additional funding, which may also influence the choice of follow-on research activity. This may involve conducting the follow-on research as proposed above in parallel to lining up the funding for a rapid development pilot program.

The ultimate goal is for the research and the framework to apply beyond the Air Force to the broader systems engineering and acquisition communities, in DoD, other parts of government, and industry.

6 EPILOGUE - ENABLERS AND INHIBITORS OF SYSTEMS ENGINEERING

This epilogue captures results that are highly related to the SME discussions, observations and findings from a recent workshop. Rapid fielding or expedited systems development plays a new role in developing systems. Instead of polishing and perfecting all requirements with possible delivery delays, these urgent needs programs must adapt themselves to have a life cycle that is driven by a "Faster, Faster and Faster" concept. Increasingly, schedule has become more important than cost. Organizations have to fight with the "time to market", "respond to competitor's threats", and "urgent needs". On one hand, project managers will not only have to find a way to make things work through the expedited lane, but also have to understand what factors are the accelerators and what are hindrances to the system development schedules. On the other hand, they have to ensure that these expedited processes will not lead to technical debt, especially in the areas of future flexibility, degradation of existing capabilities, or rework. This section will elaborate about the enablers and inhibitors and their estimated impact levels of three types of the expedited systems and software development: a) New Single System b) Existing Single System and c) System of Systems.

6.1 PRACTICAL SOFTWARE AND SYSTEMS MEASUREMENT (PSM) USERS' GROUP CONFERENCE

During the recent 16th Annual Practical Software and Systems Measurement (PSM) Users' Group Conference, we organized a workshop called *Expediting Systems Engineering within an SoS* to explore techniques and approaches to quickly engineer critical capabilities. There were 10 system and software engineering measurement experts from commercial, military/defense, and academic sectors. The workshop facilitators briefly reviewed the goals of the workshop and the critical success factors already identified as part of the RT-34 research effort. The participants were then invited to contribute to the critical success factor lists in the form of enablers and inhibitors to successful expedited systems engineering in the system of systems (SoS) environment. The "SoS environment" included new single systems that were being developed to be part of the SoS, enhancements to existing systems that are part of the SoS, and engineering at the SoS level (capability engineering).

The workshop captured 26 to 35 enablers and inhibitors for each of the system categories: new single system development, existing single system development, and SoS capability development. After the enabler and inhibitor factors were identified for each of the three categories, each attendee rated each factor "high", "medium" or "low" to indicate the level of impact each would have with respect to expediting in the respective category. Then each rating was weighted and the scores from each attendee combined to form a rank-ordered list of factors. For the few factors where the weighted scores were identical, standard deviations from the mean were used to order the factors. The following describes, in more detail, the identified enabler and inhibitor factors for new single system, existing single system, and SoS.

Expediting a New Single System

To develop a new system starting with a clean sheet of paper (e.g., a Greenfield development), the development team has considerable freedom in their choices of architecture, non-developmental items, and engineering processes. Table 6-1 lists in rank order, the expediting enablers and inhibitors associated with new single system development. With the growing use of agile and lean engineering, one might think that this would be the "silver bullet" for expedited engineering. Surprisingly this was not ranked as the enabler with the highest impact. In addition, the Greenfield development may not speed through "green lights" as quickly as one would like. As shown in the second column in Table 6-1, there are several factors that often inhibit progress and create red lights that can slow it down.

Table 6-1: Top 25 Enablers and Inhibitors for Expediting a New Single System

Rank	Enablers	Inhibitors
1	Rapid Prototyping	Requirements Volatility
2	Target hardware lab (experimentation / test lab) / test like you fly & simulation	Unprecedentedness
3	Customer /tech requirements flexibility	Delayed authority to proceed/start with fixed milestone
4	Incremental test and feedback	Infeasible schedule/staffing profile
5	Incremental Delivery & feedback	Lack of Domain Experience
6	Decision making authority	Technology Volatility
7	Best people / personnel capability	High numbers of external interfaces
8	Agile/lean approach	Vague Requirements
9	Less context switching when doing multiple projects	Under average people / Personnel Capability
10	Tools and automation	Technology Immaturity
11	Common standard, interface	Conflicting Stakeholders
12	Flexible / tailorable rules	Lack of decision making authority
13	Model-based engineering	large number of subcontractors / stakeholders
14	Building the common architecture/foundation	Lack of development infrastructure
15	Reusing assets	Rules and Regulations
16	Risk Management	Sequential Development
17	Team cohesion	Classification / sensitivity
18	Business process reengineering / process streamlining	Fear to protest the contract award resulting in poor requirements
19	COTS	Personnel Turnover
20	Overnight build	Bad RFP

First, let's discuss the green lights. Rapid Prototyping is rated as the top enabler. Rapid Prototyping can be used as project feasibility evidence or as a tool to show progress, to test a proof-of-concept, to gather feedback, to create shared knowledge, and to acquire commitment from stakeholders. Done well, an early rapid prototype of high-risk components can evolve into the actual system component, minimizing both risk and late rework, thereby compressing the development schedule. Having an integration/experimentation lab with target hardware and simulators early in the development process, can be used by the developers to converge early upon a feasible design as well as provide a mechanism to solicit stakeholder inputs and provide feedback to the stakeholders that the development is on the right track. Requirements flexibility refers to the ability to adjust or negotiate requirements if there is evidence that the original requirements are unaffordable, infeasible, or too risky. Incremental test and incremental delivery are very similar, but they are not the same. Incremental test provides feedback based on the test results from its predefined test cases. Incremental delivery provides stakeholders' feedback based on the launched or delivered product. Incremental delivery of a single system is easier to achieve compared to the near-impossible incremental delivery of a system of systems. One of the wastes in lean development is context switching. If you have to work on more than one project at a time, each time you switch the context, you will have to relearn and re-acquaintance with your new context. This task switching is really a big waste which will slow down your task and prohibit you from expediting the system development.

Inhibitors or hindrances of a new single system development are mostly the same old faces you may see in the classic risk of disasters' list. Requirements creep or requirements volatility refers to modification, addition, or deletion of the requirements during the development life cycle. The later the volatility is introduced the longer the delay it will cause to the system. Unprecedentedness challenges system engineers both in technical and non-technical perspectives. When a project is a one-of-a-kind or an avant-garde project, it is difficult for all stakeholders to check whether the product is developed correctly or good enough. In addition, extra effort needs to be spent on research, analysis of alternatives, trial-and-error, and coming up with learning curve.

Delayed authority to proceed with fixed milestone is one of a surprised, but common inhibitor. If your project has started, but you are waiting or you are not given the authority to work on the project, it will not only halt the project, but it will also cause cascading delays in all project activities. And it can be worse when you know that the deadline is approaching.

Expediting an Existing Single System

System maintenance or enhancement is used to refer to the work of modifying, enhancing, and providing cost-effective support to the existing software. System enhancement includes error corrections, functional enhancements, technical renovations, and reengineering. To enhance or extend from an existing system, some of the main constraints are current system understanding and current system architecture and foundation. The development activities could be either a major or minor modification of a product after delivery. Table 6-2 lists the enablers and inhibitors for expediting an existing single system.

Table 6-2: Top 25 Enablers and Inhibitors for Expediting an Existing Single System

Rank	Enablers	Inhibitors
1	Target hardware lab (experimentation / test lab) / test like you fly & simulation	Requirements Volatility
2	Incremental test and feedback	High numbers of external interfaces
3	Incremental Delivery & feedback	Unprecedentedness
4	Flexible / tailorable rules	Vague Requirements
5	Agile/lean approach	Embedded poor quality software
6	Rapid Prototyping	Conflicting Stakeholders
7	Common standard, interface	Delayed authority to proceed/start with fixed milestone
8	Customer /tech requirements flexibility	Infeasible schedule/staffing profile
9	Domain knowledge	Technical debt
10	Understanding of the existing system and interfaces	Interoperability / compatibility
11	Best people / personnel capability	large number of subcontractors / stakeholders
12	Less context switching when doing multiple projects	Back propagation
13	Tools and automation	Lack of understanding of the existing system and interfaces
14	Reusing assets	Under average people / Personnel Capability
15	Team cohesion	Lack of Domain Experience
16	Feasibility Evidence, Milestone review	Technology Volatility
17	Model-based engineering	Technology Immaturity
18	Colocation of hw & sw engineers	Classification / sensitivity
19	Development process tailoring/adjustment	Multiple operational sites with different configuration / platform / OS
20	Risk Management	Outdated / stovepipe technology
21	Decision making authority	Personnel Turnover
22	COTS	Lack of decision making authority
23	Business process reengineering / process streamlining	Architecture constraint / heritage
24	Outsourcing / surge support	Rules and Regulations
25	Mature configuration management	Bad documentation

Common standard or interface is one of the important enabler for system maintenance. If the existing system uses common interface prototype, it can save time in architecting the extensions. However, if the existing system is using the APIs or connectors that are outdated or uncommon, the development team needs to find out the possibility of reconnecting the new system to the existing system. Domain knowledge or knowledge about the existing system is also the key to expedited systems engineering. On the opposite side, embedding poor quality of system is one of the obvious inhibitors, which highly overlaps with Technical Debt and Back-propagation. Inheriting bad system such as bad architecture, hardcoded module, spaghetti code requires system engineers to payback the debt or even worse redo or reengineer the existing system. Unaware, having zero knowledge or lack of system understanding imposes big risks on personnel shortfall, architecture complexity, unreal schedule, and etc. Technology volatility and technology immaturity are also big inhibitors. Whether it is a turning brownfield into greenfield or continuation of greenfield, technology selection becomes constraints that the development team has to overcome and stabilize as soon as it is supported by the feasibility evidence.

Expediting a System of Systems

System of Systems Engineering (SoSE) is considered to be a multidisciplinary area and it includes management and organizational aspects as well as technical aspects of systems engineering at the System of Systems level. As these systems become larger and larger, the constituent-systems are operationally independent and managerially independent and it requires extra effort and schedule to coordinate and synchronize among several units. Table 6-3 shows the list of enablers and inhibitors ordered by their impact level.

Reuse is a possible shortcut with caveat for expedition. If those assets are designed to be reuse, it will really speed up the development process. However, if you are reusing bad assets, you will have to spend avoidable effort to fix the defects, to figure out the solution, and eventually you may end up with developing them from scratch. Team cohesion seems to affect the most in SoS since it requires high collaboration between individuals and teams. Synchronization and Stabilization will give various SoS teams peace of mind and feasibility evidence on their progress towards their goals. Common architecture and foundation is a good stepping stone to ensure that they have an established and strong backbone. It is impossible for SoS teams to collect their information by using tacit knowledge, hence Constituent Documentation would be a great enabler.

Unique inhibitors of SoS such as high number of external interfaces, infeasible schedule, large number of subcontractors, lack of communication between teams, poor/ unknown heritage/pedigree, conflicting stakeholders, reflects the nature of SoS diseconomy of scale.

Table 6-3: Enablers and Inhibitors for Expediting a System of Systems

Rank	Enablers	Inhibitors
1	Customer /tech requirements flexibility	Lack of Interoperability
2	Rapid Prototyping	Lack of / incompatible standard & protocol
3	Target hardware lab (experimentation / test lab) / test like you fly & simulation	Requirements Volatility
4	Incremental test and feedback	Unprecedentedness
5	Common standard and protocol	High numbers of external interfaces
6	Reusing assets	Infeasible schedule/staffing profile
7	Tools and automation	Inability to test across systems
8	Common standard, interface	Delayed authority to proceed/start with fixed milestone
9	Best people / Personnel Capability	Lack of Domain Experience
10	Team cohesion	Technology Volatility

11	Synchronization and Stabilization	Technology Immaturity
12	flexible / tailorable rules	Vague Requirements
13	Model-based engineering	Large number of subcontractors / stakeholders
14	Building the common architecture/foundation	Lack of development infrastructure
15	Agile/lean approach	Lack of communication between teams
16	Incremental Delivery & feedback	Classification / sensitivity
17	COTS	Poor / unknown heritage/pedigree
18	Constituent Documentation	Bad RFP
19	Decision making authority	Personnel Turnover
20	Development process tailoring/adjustment	Under average people / Personnel Capability
21	Risk Management	Conflicting Stakeholders
22	Less context switching when doing multiple projects	Poor extendibility
23	Colocation of hw & sw engineers at SOS level	Sequential Development
24	Overnight build	Overspecified requirements
25	Business process reengineering / process streamlining	Lack of constituent expert

Observation and Discussion

This section leverages the list of enablers and inhibitors by comparing the similar components and unique factors of the three systems. Table 6-4 shows top 10 inhibitors of a new single system, an existing single system, and a system of systems. As highlighted in bold and italic, these inhibitors are similar across all three systems.

Table 6-4: Top 10 Inhibitors

A New Single System	An Existing Single System	A System of Systems
Requirements Volatility	*Requirements Volatility*	Lack of Interoperability
Unprecedentedness	*High numbers of external interfaces*	Lack of / incompatible standard & protocol
Delayed authority to proceed/start with fixed milestone	*Unprecedentedness*	*Requirements Volatility*
Infeasible schedule/staffing profile	Vague Requirements	*Unprecedentedness*
Lack of Domain Experience	Embedded poor quality software	*High numbers of external interfaces*
Technology Volatility	Conflicting Stakeholders	*Infeasible schedule/staffing profile*
High numbers of external interfaces	*Delayed authority to proceed/start with fixed milestone*	Inability to test across systems
Vague Requirements	*Infeasible schedule/staffing profile*	*Delayed authority to proceed/start with fixed milestone*
Under average people / Personnel Capability	Technical debt	Lack of Domain Experience
Technology Immaturity	Interoperability / compatibility	Technology Volatility

Note: ***Bold-Italics*** similar across 3 categories, Underline reflect unique to a single category

For example, Requirements Volatility, Unprecendentedness, Delayed authority to proceed/start with fixed milestone, Infeasible schedule/staffing profile, and High numbers of external interfaces, these factors are common inhibitors that can delay any project. On the other hand, each type of system has its own specific inhibitor as highlighted in an underlined text. For a new single system, Under Average People and Technology Immaturity are the major hindrances that may not matter most in the other two systems. For an existing single

system, it is pretty clear that if the existing system has poor quality, it is a major obstacle for the system enhancement, which leads to the next unique inhibitor, technical debt. Inheriting a debt or substandard system, the system maintenance team needs to spend extra effort and schedule in refactoring or restructuring the current system and in turn prevent them from accelerating their project development. Lastly, for a system of systems, distinctive inhibitors are lack of interoperability and inability to test across systems. These two inhibitors really reflect the key basic concept of SoS. With so many systems that an SoS has to work with, if they don't have a good foundation, each system will gradually grow apart and will not only stop them from moving forward, but also force them to step back to solve the basic foundation problem. For SoS, at various points in project development, the teams need to stabilize and synchronize their works, which will provide a close loop feedback to the teams. If there is no one at check points or they are not able to check anything at milestones, it seems like the teams are walking blindly. As a result, decision makings will be delayed or uncommitable.

Similarly, there are also major overlaps in expediting enablers as reported in Table 6-5. Rapid Prototyping, Having a target lab, increment test and feedback, customer/ tech requirements flexibility are among common best practices that one can use to expedite the system development. Similar to the inhibitors, there are several enablers that contribute more in a particular system, but not at the others. An SoS requires extremely high collaboration between teams, hence it really needs a good team cohesion. For an existing single system, to know and understand the system that you have to enhance is a major accelerator otherwise the team needs to study the structure, architecture, its operational concepts and it usually takes time to come up with such a learning curve. For a new single system, since there is no problem of extending current system or extremely high number of parties to deal with, the team can really move fast if they have authority to make decision and to commit with decision and be accountable to their responsibilities.

Table 6-5: Top 10 Enablers

A New Single System	An Existing Single System	A System of Systems
Rapid Prototyping	*Target hardware lab / test like you fly & simulation*	*Customer /tech requirements flexibility*
Target hardware lab / test like you fly & simulation	*Incremental test and feedback*	*Rapid Prototyping*
Customer /tech requirements flexibility	Incremental Delivery & feedback	*Target hardware lab / test like you fly & simulation*
Incremental test and feedback	Flexible / Tailorable rules	*Incremental test and feedback*
Incremental Delivery & feedback	Agile/lean approach	Common standard and protocol
<u>Decision making authority</u>	*Rapid Prototyping*	Reusing assets
Best people / personnel capability	Common standard, interface	Tools and automation
Agile/lean approach	*Customer /tech requirements flexibility*	Common standard, interface
Less context switching when doing multiple projects	Domain knowledge	Best people / Personnel Capability
Tools and automation	<u>Understanding of the existing system and interfaces</u>	<u>Team cohesion</u>

Note: ***Bold-Italics*** similar across 3 categories, <u>Underline</u> reflect unique to a single category

In summary, this recent workshop supports continued findings on rapid enablers and inhibitors, whether developing a new system (see Chapter 4 on lanes of acquisition), modifying an existing system or working in the context of a system of systems (SoS).   Many similar themes are shown across the aspects of people, process and product.   Again, personnel capability, decision making authority, mature technologies, understanding and managing requirements are top enablers as seen in our RT-34 Framework Group 1.

6.2 Application of CORADMO Systems Engineering Tool

This section demonstrates a recent application on the use of the Constructive Rapid Acquisition and Development Model for Systems Engineering (CORADMO-SE). This case study shows the use of the CORADMO-SE model in explaining the differences in SE schedule acceleration for various project SE approaches. The baseline situation for the case study is a company division specializing in performing early-SE activities for diversified company defense applications, generally involving teams of roughly 20 SEs. The division has been traditionally applying a sequential waterfall or Vee model in defining an overall system's operational concept and requirements, and then developing a system architecture that satisfies the requirements. Defense needs for more rapid SE have led the division to change to a concurrent agile approach.

The baseline situation for the division is shown in the yellow (shaded) M boxes in Table 6-6. The usual systems' product factor ratings are: are moderately complex; sufficiently diverse to make reuse infeasible; non-subsettable so that low-priority deferrals are infeasible; only able to use models vs. documents 15% of the time; and involving only one or two slightly immature (TRL 6) technology elements. This latter is the only factor enabling a schedule reduction (down to 0.92 of the nominal). The other three factors will increase the required schedule, by a factor of (1.09)*(1.09)*(1.05) = 1.25. Overall, the overall impact of the usual system's product factors on SE schedule is an increase of (1.25)*(0.92) = 1.15.

The usual systems' three process factor ratings (highly sequential SE processes; largely bureaucratic internal and external project and business processes; moderate SE tool coverage, integration, and maturity: CIM) create another net schedule stretch out of (1.09)*(1.05)*(0.96) = 1.10. Their usual systems' four project factors (project SE staff size between 10 and 30 people; good collaboration support across several metro-area facilities; moderate CIM for single-domain MMPTs; and minimal CIM for multi-domain MMPTs) account for a net schedule compression of (0.96)*(0.96)*(0.96)*(1.04) = 0.92.

Their people's knowledge, skills, and agility (KSAs) overall ratings for general SE, single-domain SE, multiple-domain SE, and team compatibility account for a net schedule compression of (0.94)*(0.94)* (1.06)*(0.94) = 0.88. The projects are evenly balanced between risk-aversion and risk acceptance, leading to a multiplier of 1.0 and no effect on the schedule. Overall, then, the baseline case comes very close to the nominal schedule, multiplying together to (1.15)*(1.10)*(0.92)*(0.88)*(1.0) = 1.024.

Table 6-6: CORADMO-SE Schedule Drivers and Multipliers

Accelerators/Ratings	Very Low	Low	Nominal	High	Very High	Extra High
Product Factor: Multipliers	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity	Extremely complex	Highly complex	Mod. complex	Moderately simple	Highly simple	Extremely simple
Element Reuse	None (0%)	Minimal (15%)	Some (30%)	Moderate(50%)	Considerate((70%)	Extensive (90%)
Low-Priority Deferrals	Never	Rarely	Sometimes	Often	Usually	Anytime
Models vs Documents	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Key Technology Maturity	>0 TRL 1,2 or >1 TRL 3	1 TRL 3 or > 1 TRL 4	1 TRL 4 or > 2 TRL 5	1-2 TRL 5 or >2 TRL 6	1-2 TRL 6	All > TRL 7
Process Factor: Multipliers	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	Highly sequential	Mostly sequential	2 artifacts mostly concurrent	3 artifacts mostly concurrent	All artifacts mostly concurrent	Fully concurrent
Process Streamlining	Heavily bureaucratic	Largely bureaucratic	Conservative bureaucratic	Moderate streamline	Mostly streamlined	Fully streamlined
General SE tool support CIM (Coverage, Integration, maturity)	Simple tools, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Project Factors: Multipliers	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)	Over 300	Over 100	Over 30	Over 10	Over 3	≤ 3
Collaboration support	Globally	Nationally	Regionally	Metro-area	Simple campus,	Largely

	distributed weak comm. , data sharing	distributed, some sharing	distributed, moderate sharing	distributed, good sharing	strong sharing	collocated, Very strong sharing
Single-domain MMPTs (Models, Methods, Processes, Tools)	Simple MMPTS, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Multi-domain MMPTs	Simple; weak integration	Minimal CIM	Some CIM or not needed	Moderate CIM	Considerable CIM	Extensive CIM
People Factors: Multipliers	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)	Weak KSAs	Some KSAs	Moderate KSAs	Good KSAs	Strong KSAs	Very strong KSAs
Single-Domain KSAs	Weak	Some	Moderate	Good	Strong	Very strong
Multi-Domain KSAs	Weak	Some	Moderate or not needed	Good	Strong	Very strong
Team Compatibility	Very difficult interactions	Some difficult interactions	Basically cooperative interactions	Largely cooperative	Highly cooperative	Seamless interactions
Risk Acceptance Factor: Multipliers	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
	Highly risk-averse	Partly risk-averse	Balanced risk aversion, acceptance	Moderately risk-accepting	Considerably risk-accepting	Strongly risk-accepting

The SE division's initial change to a concurrent agile process approach changes some of the yellow boxes in the rating scales to red (Table 6-7). For example, going from sequential SE to doing 3 artifacts (Operational Concept, Requirements, and Architecture) mostly concurrently, reduces the schedule from a slowdown factor of 1.09 to a speedup factor of 0.96, or a net speedup of 0.96/1.09 = 0.88 of the baseline schedule.

However, what actually happened was an SE schedule slowdown factor of about 15%. In trying to understand the reasons for this, the company did a CORADMO-SE analysis of all of the SE schedule influence factors. The analysis found that the <u>transition to an agile SE approach was flawed in several ways</u>. Some were missed opportunities by addressing only some of the improvable SE schedule influence factors, but not others, such as the largely bureaucratic internal and external project and business processes, and the Low-rated multi-domain MMPTs and KSAs. Others were due to experiencing some frequent pitfalls in transitioning from sequential, heavyweight processes to agile processes, as seen in the other red boxes:

- Key Technology Maturity. One of the pitfalls in agile development is premature commitment to attractive but immature solutions such as commercial-off-the-shelf (COTS) products. These later require considerable extra work and delays to fix or replace. The change to a Nominal from a Very High rating caused a slowdown factor of 1.0/0.92 = 1.09
- General SE tool support. Using a mix of agile SE tools and their traditional SE tools made their SE tools less integrated, for a slowdown factor of 1.0/0.96 = 1.04.
- General SE KSAs. Their SE people were still coming up the learning curve in their agile-SE KSAs, for a slowdown factor of 1.0/0.94 = 1.06
- Team Compatibility. Some of their management personnel continued to use traditional approaches, contributing another slowdown factor of 1.0/0.94 = 1.06.

As a result, the CORADMO-SE estimate of their net slowdown factor was (0.88)*(1.09)*(1.04)*(1.06) *(1.06) = 1.13. Thus, the CORADMO-SE analysis not only explained their SE schedule slowdown factor of about 15%, it also provided them with a roadmap of further agile SE improvements they could make to begin to experience agile SE speedups, along with estimates of the impact these would have on their SE schedules.

Table 6-7: Initial (Red) and Subsequent (Green) Agile Changes to the Corporate Baseline Ratings

Accelerators/Ratings	Very Low	Low	Nominal	High	Very High	Extra High
Product Factor: Multipliers	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity	Extremely complex	Highly complex	Mod. complex	Moderately simple	Highly simple	Extremely simple
Element Reuse	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Low-Priority Deferrals	Never	Rarely	Sometimes	Often	Usually	Anytime
Models vs Documents	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Key Technology Maturity	>0 TRL 1,2 or >1 TRL 3	1 TRL 3 or > 1 TRL 4	1 TRL 4 or > 2 TRL 5	1-2 TRL 5 or >2 TRL 6	1-2 TRL 6	All > TRL 7
Process Factor: Multipliers	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	Highly sequential	Mostly sequential	2 artifacts mostly concurrent	3 artifacts mostly concurrent	All artifacts mostly concurrent	Fully concurrent
Process Streamlining	Heavily bureaucratic	Largely bureaucratic	Conservative bureaucratic	Moderate streamline	Mostly streamlined	Fully streamlined
General SE tool support CIM (Coverage, Integration, Maturity)	Simple tools, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Project Factors: Multipliers	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)	Over 300	Over 100	Over 30	Over 10	Over 3	≤ 3
Collaboration support	Globally distributed weak comm. , data sharing	Nationally distributed, some sharing	Regionally distributed, moderate sharing	Metro-area distributed, good sharing	Simple campus, strong sharing	Largely collocated, Very strong sharing
Single-domain MMPTs (Models, Methods, Processes, Tools)	Simple MMPTS, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Multi-domain MMPTs	Simple; weak integration	Minimal CIM	Some CIM or not needed	Moderate CIM	Considerable CIM	Extensive CIM
People Factors: Multipliers	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)	Weak KSAs	Some KSAs	Moderate KSAs	Good KSAs	Strong KSAs	Very strong KSAs
Single-Domain KSAs	Weak	Some	Moderate	Good	Strong	Very strong
Multi-Domain KSAs	Weak	Some	Moderate or not needed	Good	Strong	Very strong
Team Compatibility	Very difficult interactions	Some difficult interactions	Basically cooperative interactions	Largely cooperative	Highly cooperative	Seamless interactions
Risk Acceptance Factor: Multipliers	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
	Highly risk-averse	Partly risk-averse	Balanced risk aversion, acceptance	Moderately risk-accepting	Considerably risk-accepting	Strongly risk-accepting

The company's agile-SE improvement goals included restoring the red slowdown factors to their baseline yellow rating levels, which would eliminate an overall slowdown factor of (1.09)*(1.04)*(1.06) *(1.06) = 1.29. They also included further initiatives shown by the green boxes, to:

- Perform concurrent V&V along with concurrent Operational Concept, Requirements, and Architecture activities, for a speedup factor of 0.93/0.96 = 0.97
- Improve their largely bureaucratic internal and external project and business processes to be at least moderately streamlined, for a speedup factor of 0.96/1.04 = 0.92.

If they could achieve all of these goals, they could achieve a speedup factor of (1.024)*(0.97)*(0.92)/1.29 = 0.71. Their first attempt to do this did not achieve the full impact, but brought them to a 15% speedup factor and subsequent efforts brought them to a 29% speedup factor.   Thus, the CORADMO-SE model helped them achieve their goals, and beyond that indicates initiatives that could speed up their SE activities even further.

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APPENDICES

APPENDIX A: METHODOLOGY

A.1 RESEARCH DESIGN AND METHODOLOGY

The main focus of RT-34 is to create a framework for expedited systems engineering for rapid capability and urgent needs. The research team set out to discover consistent or unique attributes of rapid organizations and their systems engineering processes. How do these organizations field military capabilities in a significantly reduced time than the time it takes to field a traditional product? What products do they develop? What systems engineering processes and practices do they follow? What are their teams like? Is there a "secret sauce" to systems engineering? Are they just breaking all the real and perceived rules of traditional acquisition? How do they tailor these rules for their situation?

The overall research method is based on grounded theory. Grounded theory is a type of qualitative research methodology that allows theories to emerge from the collected data. The research is based on over 30 case studies of organizations performing rapid development on U.S. military urgent needs programs, in which field data was collected and initial theories developed. The case studies were selected to understand how these organizations work, what they do, and what critical success factors may be involved with their work.

This approach is useful for research problems that are complex and about which there is little measurable data (e.g. organizational and/or sociotechnical systems). Further, many organizations responding to Joint Urgent Operational Needs Statements (JUONS) are conducting classified work and therefore public information about their organization and projects are unavailable. Conducting in-person site visits also allowed the opportunity to visit facilities, meet project personnel, and visually experience how the organizations conducted business.

The collection of data comes from notes during discussions with the leadership of these "rapid" organizations— essentially subject matter experts (SME) in the field—to discern what made them successful and discover what drove their systems engineering processes.

The research team developed questions that were very engineering focused, to examine the Systems Engineering technical and technical management processes (e.g., risk, requirements, technical decision making, modeling, documentation, etc) as well as the product or solution architecture (e.g., interfaces, technical maturity, complexity, etc). The responses, however, nearly always pointed back to the people, who had a set of career experiences and a way of thinking that enabled them to make appropriate judgment calls on what systems engineering was needed, and that this process was enabled through the culture and leadership of the organization. The responses could be interpreted by the researchers, and the reader, to better describe system development or system acquisition, than strictly systems engineering.

The research follows a systematic, yet flexible process to collect data, code and analyze the data, make connections, and see what theories can be generated. This "open coding" of labels is an important part of the analysis concerned with identifying, naming or labeling, categorizing, and describing phenomena found in the discussion notes. In this case, the theory is a set of principles for successful rapid acquisition.

Once the initial principles were identified from the data analysis of the discussions, the research team collected them together to see whether they made sense and whether the principles were "new" compared to what is already known in the literature and by the researchers' previous experience and knowledge of practices in other

fields. The researchers also reviewed other SERC Research Tasks to identify methods, processes, and tools (MPTs) or other research findings and results that could apply to rapid development. Many of the principles used by rapid organizations were validated in the literature search to be practices seen in other fields. Principles were then collated into observations. Finally, the researchers analyzed what these practices meant, collected them into a framework, and identified findings and recommendations for each group of the framework.

The researchers iterated one time with the SMEs to ask them to review the draft report and validate the framework. We asked the following questions and aggregated the responses received:

- What sections of the report did you read?
- Does the report reflect what you told the researchers?
- What level of the framework best reflects your organization?
- How would you rate the framework's usefulness for developing junior personnel?
- How would rate the framework's applicability to non-rapid traditional acquisition?
- What are the top 3 of the 11 findings that you feel are the most important?
- Do we have permission to list your organization in the final published report? Organizations interviewed will appear in the report. All other identifying information in the report has been aggregated.
- If so, how would you like your organization listed?

In addition, the researchers gathered feedback on the iterative development of the framework at the NDIA Systems Engineering Conference (October 2012, San Diego) and at the AIAA Space 2012 Conference (Pasadena, CA), and socializing (informal discussions) with other members of the rapid development community in both government and industry. Several interim meetings were held with the Air Force sponsors to further gather input from them on the user community and possible follow-on research. Finally, a "deep dive" review was held with SERC leadership and several collaborators to review the research methodology and framework and to discuss potential future research questions. The feedback received was incorporated into this final report. Two journal articles are being prepared and submitted, to the IEEE Systems Journal and the INCOSE Systems Engineering Journal. Once those articles are accepted and published, this final report will be approved for public release.

The overall RT-34 research approach is shown in the Figure A-1.
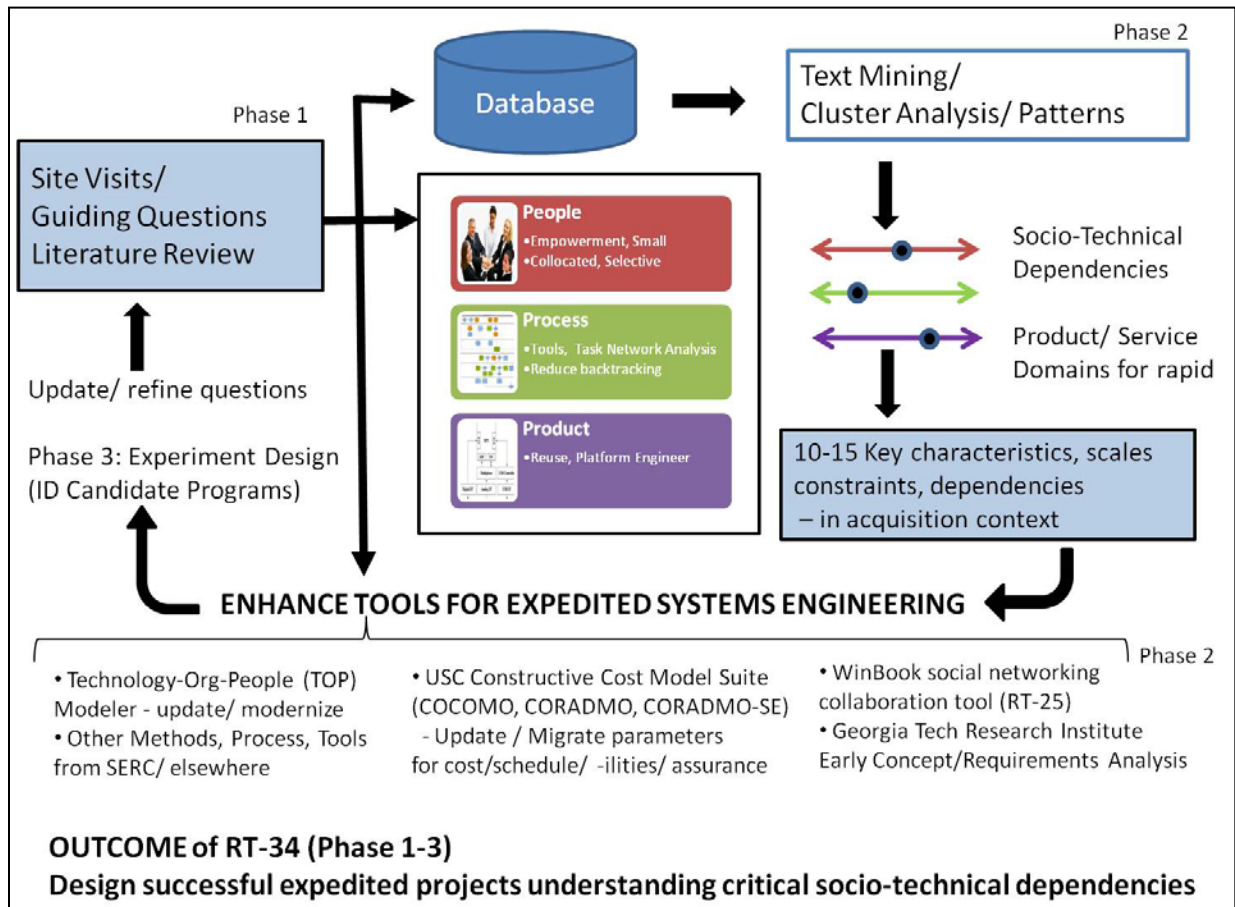
Figure A-1: RT-34 Research Design and Methodology

Discussion of Human Subjects Research

DoD issued a rule amending the Defense Federal Acquisition Regulation Supplement (DFARS) to address requirements for the protection of human subjects involved in research projects: "Researcher shall not commence performance of research involving human subjects that is covered under 32 CFR Part 219 or that meets exemption criteria under 32 CFR 219.101." The definition of *Human Subject* means a living individual about whom an investigator (whether professional or student) conducting research obtains (1) Data through intervention or interaction with the individual, or (2) Identifiable private information.

This research sought to talk with organizations that practice rapid development. Contacts were made at the leadership level of these organizations, through contacts made as described earlier. In all cases, an email was sent with an overview of the research and a list of guiding questions for a site visit or conversation. Thus, the purpose of the research was known up front, and all organizations had the option to meet with us or not. Throughout this research report, the words "interview" or "survey" is used colloquially, for lack of a better term. These terms are used to convey open discussions with, sometimes self-volunteered, organizations and SMEs, to collect data about acquisition projects, processes and best practices, not the human subjects. These "conversations" evolved in real time, and each conversation was different depending on what the SME wanted to discuss. In many cases, the site visits consisted of organizational standard briefings (i.e., "this is how we do business"). The conversations were focused at the organizational level, not on individual projects or personnel.

Identifiable private information was never obtained nor solicited. Likewise, data about these SMEs was never obtained nor solicited. For example, some questions pertained to the solution or product characterization of an acquisition project. One finding was to reduce time, always search out legacy components (possibly flight-certified) or modify existing legacy platforms. Another question was on the organization of work during the acquisition project. This led to the finding to organize with small (10-12) person teams, made up of specific skills appropriate to the project. As the observations show, when matched with a literature search, many of the findings are not new.

Further, some of these organizations required visit requests for the facility, even though all conversations were conducted at the unclassified level. The act of requesting and submitting a visit request demonstrated the volunteer nature of the visits on the part of the organization. In fact, several organizations commented that they were more than willing to talk to us, because this was one of the rare times where they could talk about rapid development with people who "understood them."

The need for an Institutional Review Board (IRB) to screen and review the data collection, storage and processing protocols was deemed unnecessary. At the same time, however, we took care to practice good data collection because we were aware of the possibility that interviews with US companies, DoD organizations and non-US companies may inadvertently introduce data potentially subject to export control restrictions. Therefore, we implemented protocols to protect distribution of raw notes and to separate interview notes from the organizations and individuals. After complete review, it was determined that no export control data was collected, as only systems and marketing level information was obtained. We maintained the protection and separation as part of good practice.

A.2 RESEARCH PHASES

RT-34 research began September 1, 2011, with the predominance of the data collection and analysis completed by September 30, 2012, with time designated until December 31, 2012 to review the findings and confirm the next phase of research. The research dollars were such at the Stevens and USC collaborators were funded through December 31, 2012, and AFIT's support ended September 30, 2012.

The RT-34 research followed the following phases, which were set at the beginning of the research:

- Phase 1: Short planning phase to identify organizations practicing expedited systems engineering, including visiting selected organizations and incorporating input from the SERC Research Council.
- Phase 2: Analyze current state of the art in expedited systems engineering within DoD as well as non-DoD and commercial sector, and developing a framework for scaling SE activities in response to different development constraints, such as reduced development time.
- Phase 3: Prepare a plan for both validating the framework on a DoD acquisition program, or plan for follow-on research.
- Phase 4: (Future, Separate Funding): Execute the plan from Phase 3, with research to analyze the framework in action and iterate it based on observations and results as applied to a real program.

The Phases were conducted in parallel, and the research evolved as the site visits were conducted, additional data were collected, and observations were iterated. Further, the site visits shifted from considering DoD, non-DoD and commercial sectors to a focus on government defense organizations, with a predominant representation from the Air Force.

As seen from the report in Chapters 2-4, the research also evolved, based on the responses from site visits, to consider the broader context of the people, processes, and products involved in rapid development. This required some additional inferred observations from the research, because the responses did not always directly answer how systems engineering was expedited.

Although we identified several methods and candidates for validating the framework on a DoD acquisition program, we discovered that the framework was not mature enough to immediately do so. Additional research questions arose that, once addressed, would enable the validation as originally intended or perhaps validation in a new way of one of the new findings. The additional research questions are addressed in Chapter 5 of this report.

A.3 IDENTIFICATION OF CASES FOR SITE VISITS AND INTERVIEWS

The first step was to identify organizations conducting rapid development. Organizations were selected on the basis of their:

- Identified role in urgent needs projects (preferably responses to U.S. military JUONS)
- Known ability to conduct rapid development
- Access to the organization, such through the sponsor, researchers, or referral from another organization
- Willingness to participate in the research.

The list of rapid organizations to interview began with organizations recommended by the SERC Research Council, the SERC sponsor, the Air Force sponsor, personal contacts known by the PI and co-PIs, and rapid cell organizations identified in Defense Science Board (DSB) and General Accounting Office (GAO) reports. Over time, new organizations were identified based on recommendations from the Pentagon Systems Engineering Forum and the SMEs themselves. (This "referral" process in itself validated one of the observations of the circle of trust.)

In nearly all cases, case studies were conducted at the headquarters or program level, not at the project level. This allowed insight into the how the organization responded to JUONS or conducted rapid development. Conducting in-person site visits also allowed an opportunity to tour facilities, meet additional personnel, and visually experience the dynamics of the organization. Naturally, further research may determine any biases between management and engineering in their answers; however, because these project teams and organizations were relatively small and flat, we hypothesize this is may not be a strong nuisance factor.

Each case was presented with a set of open-ended questions regarding critical success factors of their organizations and examples of successful rapid development projects. Cases were provided with the list of questions by email, and a follow-up meeting was scheduled. Discussions were conducted in person, with one or two conducted over the phone or with one researcher on the phone and another in person. The researchers held one to two hour conversations with each organization (ranging from a single representative to a small group of senior leaders) and did not focus on specific programs or projects.   In some cases, written responses or briefings were provided by the organization. Some individuals requested that their name and organization be kept confidential. In all cases, organizations were willing to respond to questions and have a discussion knowing that the responses and data would be aggregated together with those from other site visits.

Over 30 discussions with organizations and individuals were conducted, mostly from the government and military. (See section A.5 for more detail.) The notes from these discussions were coded and tagged based on patterns of consistent responses.

Initially, the list of organizations included government (both defense and civil) and commercial entities. As time went on, however, it became clear that the government organizations were different, and in particular, the military ones were different than the civilian ones. The sponsor expressed a preference for focusing on military urgent needs organizations, because this was the population of interest. These organizations were also more consistent with the RT-34 Phase 3 and Phase 4 future research intent to validate an expedited SE framework on a DoD acquisition program.

The full list of site visits is shown in Table A-1, which reflects 25 locations, some with discussion with multiple SMEs. The list is in chronological order, showing the increased focus on defense and Air Force organizations as the research progressed.

In total, the 25 site visits represented:

- 15 government defense and intelligence community, of which 10 were Air Force
- 4 industry (all 4 conduct work for defense, civil, and commercial customers)
- 1 government civil space
- 1 Federally Funded Research and Development Center (FFRDC)
- 1 educational institution
- with the remaining 3 "site visits" conducted at conferences incorporating multiple individuals from all of these sectors.

Note that examining the characteristics of military organizations – particularly on how they are organized and conduct business – is an area of potential future literature search and research. Such characteristics may include the government acquisition process and rules; Volunteer "army"; officers, enlisted personnel, civilians, contractors; and the government role as acquirers and operators not the builders.

A.4 DEVELOPMENT OF QUESTIONNAIRE

Lane et al. 2010 examined critical success factors of five different organizations developing rapid, innovative solution and concluded that successful, high performance organizations share certain characteristics in the development of innovative systems:

- Driven by business value
- Take calculated risks
- Proactive management and small agile teams
- Look for solution patterns that can be re-used
- Follow concurrent engineering practices
- Provide culture and environment that supports innovation.

These findings parallel Kelly Johnson's famous "14 Rules of Management" developed in the Lockheed Skunk Works program, where his motto was "Be quick, be quiet, and be on time." [Johnson]

The questions posed by Lane et al [Lane et al 2010] became the starting point for the lines of inquiry to the organizations selected as case studies. The expedited SE research used these basic factors as a guide and created a new list of questions to go into the next level of detail of "why" or "how" a characteristic may be important. The list of questions guided open discussions, and did not specifically force closed responses to each question.

The original list of expedited questions is in Attachment 1.

A.5 REFINEMENT OF QUESTIONS

Within the first week of interviews, obvious patterns began to emerge from the interviews. These patterns were clustered into 4 major categories: product, process, people, and project. The questions were iterated based on these questions. This process is typical of a pilot test of questions. The questionnaire shown in Attachment 2 was used in all other interviews to date.

As the questions are open-ended, each interview was allowed to proceed according to the desire of the SME and the line of answers that emerged during the discussion.

A.6 COLLECTION OF DATA INTO DATABASE, DATA MINING & CLUSTER ANALYSIS

Notes were hand-written by the researchers during the site visits. Many of the organizations were in secure facilities, and thus recording devices were not permitted. Hand-writing of notes can introduce human error and unintended bias into the data collection. For example, the researcher could miss an important word, translate words into his or her own words, or hear the same words multiple times and stop writing it down (thinking: "I already have that point").

An Access Database was developed to collect the site visit data. The database tags the responses according to the four categories (product, process, people, and project), with further tags of key words that emerged as patterns in the interview. All organizations and interviewees were coded such that the identities were obscured.

Notes from over 30 discussions with government and industry rapid organizations and individuals were input to the database. Notes were transcribed word for word into the database, with one person doing the transcription. In cases where multiple researchers were present at a site visit, the transcriber would compare the notes and merge them together. This was not a perfect process, as the transcriber could have misinterpreted the notes. To mitigate this potential error, one researcher reviewed all the notes and the database for consistency and to remove any duplication. This same researcher was present in all but one of the discussions, and thus was in the best position to make this judgment call on the notes.

These words were also inserted into "Wordle," a on-line, free word count software, to visualize any initial patterns in a word cloud. The purpose of using this qualitative tool was to give a visual representation of prominent words from the interviews, allowing initial insight to key words and patterns. This visualization was not used to determine the 11 direct response observations described in Chapter 2.

The following two figures show the Wordle diagram at two points in time. The first figure is in March 2012, with 14,500 words from site visit notes. This shows "requirements" being prominent.

The second figure is from July 2012, when the full set of notes had been captured in the database, with over 23,000 words from the notes. At this point in time, with a more complete database, "people" shows up as the most prominent word.

Figure A-2: Word Cloud of Over 30 Interviews with Gov't/ Industry Rapid Acquisition Organizations, with Over 14,500 words from interview notes (as of March 2012)

Figure A-3: Word Cloud from Over 30 Interviews of Gov't/ Industry Rapid Acquisition Organizations, with Over 23,000 words from interview notes (as of July 2012)

The results of the word cloud are simplistic, as some words are repeated in singular and plural form, or with capital letters, and thus the true patterns may be even stronger than this represents. For example, "requirements" appears as the most dominant word in the first figure. By treating Requirements (capital R), requirement (singular), and Requirement (capital R and singular) all as the same word, "requirements" may appear as an even stronger pattern. The same can be said for the next strongest word: "People." There are several words that may be synonyms for people, such as customer contractor, leadership, experts, etc.

Therefore, a more sophisticated qualitative analysis was needed, and a cluster analysis was conducted of the interview data using the commercially available "ATLAS.ti" qualitative data analysis tool. The research question for this analysis was: *Is there a common set of practices that drive the business model of rapid organizations?* The intent was to identify key patterns to determine the most prevalent themes and the correlation of certain words.

The hypothesis was that rapid acquisition processes are governed by a common set of principles. Via interview sessions with these organizations, the expected outcome is an emergence of these common governance principles. Potential second order effects are that expedited SE and rapid acquisition concepts could improve processes for traditional programs.

The first round of analysis looked at frequency of words and correlations, in total of all interviews. This resulted in the identification of 12 principles that were documented by the AFIT master's students for their research report. (Ford et al, 2012) As a result of inputs from reviewers during the defense of their report, a second round of analysis was done examining the frequency of words and correlation per organization.

A complete description of the ATLAS.ti™ data analysis methodology and results is in Appendix B.

The principles were narrowed down to 11 direct observations of "Group 1," as described in Chapter 2.

A.7 CREATION OF THE FRAMEWORK

An original goal of the RT-34 research was to develop a framework for scaling SE activities in response to different development constraints, such as reduced development time, with intent to prepare a plan to validate the framework on a DoD acquisition program. The framework evolved in an iterative process, using a grounded theory approach.

The framework development began in parallel to the data collection and evolved based on the results of the site visit data collection, data analysis, the literature search, the review of other SERC RTs, the review of other known MPTs, and the researchers' knowledge of practices in other fields. As a result, a framework began to emerge that describes rapid development.

Our first framework was based on the "lanes of acquisition" as described in Chapter 3. The concept came about early on, as it appeared that the approach to expedited SE depended on what product was intended and what systems engineering processes were tailored or scaled accordingly. The product implied a "lane" of acquisition, and the lanes could also be associated with varying levels of systems engineering rigor. We socialized this concept, along with the sponsor, at the Conference on Systems Engineering Research (CSER) 2012 in two separate plenary keynote presentations, as well as with various discussions with SMEs in the community and with the SERC sponsors.

After gathering feedback, we realized that the "lanes" were a subset of a larger framework, and not the answer itself. (The lanes and flexibility ultimately became a "Direct Observation" of Group 2.) The research team met as a group for several days in July 2012 to debate this framework. The second iteration resulted in a stacked "triangle-shaped" model, collecting the observations from the data along with our own interpretation of the data. This implied a hierarchy of activities conducted by rapid organizations, with increasing rigor of systems engineering and sophistication. However, the concept of a hierarchy raised an additional research question, as we did not have the data to prove a hierarchy. It was this first triangle model that was included in the first draft of the final report and distributed to all the site visit organizations and individuals for feedback, as described earlier.

We incorporated all the feedback received and reviewed the final report draft 2 with the sponsor. Through this preparation and discussion, we realized that some parts of the framework described "what" organizations did, and other parts described "how" they did them. The framework should be consistent, and we restructured the framework to consist of "whats" and moved the "hows" to an appendix and described them as enablers. We were also challenged to think about what would make the framework useful to the rapid acquisition community (who would say our observations were "not new") and how to make it resonate with the traditional acquisition

community (who were typically biased against rapid programs because they felt that rapid programs operated outside the DODI5000 rules). A third iteration, still in a triangle shape, resulted, along with the shaping of future research questions that would address how to expose and educate the acquisition community to accelerated development, hypothesizing that the experiences gained in a rapid program could give engineers and contracting officers alike a better understanding of a full acquisition cycle and the goal to enable a warfighter to deliver a desired effect. This goes beyond just learning how to follow a proscribed process.

We then shared this triangle shape with attendees to our presentation at the NDIA Systems Engineering Conference (October 2012). We were looking for feedback on whether the framework resonated with other SMEs in the community, and whether we could gather any insight to reasonableness of a hierarchy. The framework was also informally socialized in another site visit with a DoD rapid cell that was not part of the initial site visit group. Further feedback was gathered at the SERC Sponsor Research Review in November 2012 through a SERC panel. The feedback was positive, and we kept the triangle, and documented the further research questions that it prompted (as described in Chapter 5) such as hierarchy, questions of what was necessary and sufficient for success, etc.

The last iteration is presented in this final report and came about from further discussions with the RT-34 research team as well as a "deep dive" review and discussion with SERC leadership and collaborators from other related RTs. We finally elected to not infer any precedence, hierarchy, or increasing systems engineering rigor in the framework. We eliminated the triangle shape and re-ordered the groups to describe exactly what we saw in this research project.

For presentation in this report, we break the framework into three groups:

- Group 1: Direct Responses,
- Group 2: Direct Observations, and
- Group 3: Inferred Organizational Characteristics.

The Direct Responses in Group 1 provide an efficient affinity across all answers to our 37 questions. This set represents the top 11 "Organizational Best Practices". We observed strong evidence across the site visits for all 11 observations. In the process of validating the responses with the SMEs, reviewing against literature, and socializing the observations with others in the rapid and traditional community, we realized that the 11 observations are "not new" and do not appear to be unique to rapid programs. We characterize these as practices that can be found in both rapid and traditional development programs.

Group 2 "Flexible Acquisition Practices" reflects Direct Observations that emerged from the site visits, but were not direct responses to the prepared questions. This group collects observations based on flexibility in acquisition practices, whether it be contract type, finance type, program management approach, documentation required, level of insight/oversight, etc. These practices are seen as critical for a rapid business environment. We originally did not seek out different types of rapid categories, or strictly acquisition management (such as contracting) findings; in fact, a ground rule of the research was that we would not seek to change the existing DoD5000 process. However, these observations about the acquisition environment emerged from the site visits and could not be ignored.

Group 3, the set of "Inferred Organizational Characteristics," represents aspects of a "Go Fast" Culture seen in the rapid organizations. This is where rapid organizations start to differ from traditional ones, and there is a shift in energy, commitment, and knowledge. These findings are motivated by an analysis of effective enterprise culture and business agility literature.   The Group 3 characteristics include:

- Rapid organizations use intense and efficient knowledge-sharing to enable stabilization and synchronization of information
- Rapid organizations are characterized by a risk-tolerant culture
- Rapid organizations are structured for ambidexterity with a balance between exploration and exploitation
- Rapid Development organizations exercise Real-time Management, with both empowerment at the lowest level at which sufficient knowledge and experience exists to make appropriate decisions as well as rapid access to top-level leadership to facilitate decision velocity.

Real-time management represents an integrative characteristic; it requires intense knowledge sharing, risk-focused culture (people knowing what risks to take and when and how), and the organizational ambidexterity that comes from a balance of exploration and exploitation.

The framework could and likely will continue to evolve as this final report is socialized within the SERC collaborator and sponsor community, and as future research questions are addressed in the follow-on activities.

A.8 LIMITATIONS AND ASSUMPTIONS

The qualitative nature of this data and grounded theory research allows for interpretation depending on the readers or researchers point of view. Qualitative analysis can therefore become biased based on individual experience and perspective. The research team endeavored to stay aware of bias in guiding discussions and interpreting data. Further, the interviews were conducted as guided conversations as opposed to strict survey responses. The research team ensured the topic of each question was covered within the course of each conversation and felt better data was acquired by allowing the SMEs to discuss the organization and its processes in their own way. As noted in Section A.6 above, errors could also be introduced during the note-taking and transcription processes.

The data analysis with ATLAS.ti™ tool analyzed data from a sub-set of the interviews—covering 22 different interviews and briefings. Informal discussions and note taking from conferences were not included in this analysis. This is because while target of opportunity and short notice interviews afforded great openings for data gathering, they did not result in complete sets of notes. Further, not all team members were able to attend all discussions. The first round of data analysis was conducted by the AFIT student team, which limited the data sets to those interviews they personally conducted or those with which they had considerable background information to provide interview context.

Many of the organizations interviewed were managing classified programs with classified customers. All interviews were conducted in an unclassified environment. This may have limited the extrema of detail provided and potentially prevented full disclosure of organizational practices. Further, this precluded detailed discussions on specific products these organizations have delivered or are developing at the time of the interview. Discussions held in secure facilities did not permit recording devices, so all notes were hand-written, which could introduce biases as described earlier.

As a part of the literature search, various Systems Engineering case studies from both traditional and rapid organizations were analyzed in an attempt to map real-world data back to the proposed framework. This proved to be difficult, as existing case study data (such as AFIT published case studies) were not geared to address the question of success according to this framework. Further, the RT-34 interviews themselves did not specifically ask whether and how certain principles resulted in success or failure.   The questions assumed that the rapid organizations were successful in what they did. Delving into these questions would require collecting data from specific programs or projects in which the definition and metrics of success or failure could be further explored. This is an area for future research.

A.9 SUMMARY

RT-34 provides an initial basis to understand U.S. military urgent needs programs and how they conduct rapid development. RT-34 hypothesized that rapid acquisition organization success is governed by a common set of principles and that via interview sessions with these organizations, common governance would emerge. Through the analysis, a common set of principles did emerge and attempts are already being made to apply some of them to traditional acquisition programs.

It is an underlying assumption that the organizations interviewed achieved success in some right, whether that be cost, schedule, or delivering a product to the field. Attempts were not made to explicitly define success in these organizations, but rather assume that by their very nature and existence, they are successful in some way. While the original hypothesis sought to identify critical success factors, the interviews and data analysis have revealed principles and common themes, but not whether the themes would be necessary or sufficient for success. This is an area for further research.

Table A-1: List of Site Visits Conducted

1	The Aerospace Corporation Concept Design Center (CDC), Los Angeles, CA
2	American Institute of Aeronautics and Astronautics (AIAA) Space 2011 conference, Long Beach, CA (various discussions with SMEs from government, industry, and academia)
3	An aerospace industry innovation lab, Southern California
4	A rocket engine design company, Southern California
5	Annual SERC Research Review (ASRR), College Park, MD (various discussions and presentation notes, including a panel discussion on this research subject)
6	Small satellite development company
7	NASA Goddard Space Flight Center (GSFC), Greenbelt, MD (multiple separate discussions)
8	Operationally Responsive Space (ORS) Office, Kirtland AFB, NM (multiple discussions)
9	USAF Space Development and Test Directorate, Kirtland AFB, NM (multiple discussions)
10	Int'l Symposium for Personal & Commercial Spaceflight (ISPCS) (several discussions w/speakers & attendees)
11	International Women's Forum Annual Conference, Washington, DC (notes from panel presentation)
12	Air Force Rapid Capabilities Office (RCO), Washington DC
13	Intelligence Community, Washington DC (multiple organizations represented)
14	Georgia Tech Research Institute (GTRI) Collaborative Visualization Environment ("COVE"), Atlanta, GA
15	U.S. Army Prototype Integration Facility (PIF), Huntsville, AL
16	Aerospace / Engineering small business, Huntsville, AL (multiple discussions)
17	Big Safari - Program office and AF Program Executive Office, ISR-SOF, Wright-Patterson AFB OH
18	Air Force Research Lab (AFRL) Center for Rapid Product Development (CRPD), Wright-Patterson AFB, OH
19	AF Aeronautical Systems Center, Rapid Development Integration Facility (RDIF), Wright-Patterson AFB, OH
20	AFRL Air Vehicles Directorate, Wright-Patterson AFB, OH (multiple discussions)
21	Air Force Space Command / A5, Peterson AFB, CO
22	Air Force Space and Missile Systems Center, Rapid Reaction Branch, Colorado Springs, CO
23	Air Force Tactical Exploitation of National Capabilities (TENCAP), Schriever AFB, CO
24	Air Force Space and Missile Systems Center HQ, Los Angeles, CA
25	SOCOM Research and Development Acquisition Center (SORDAC), MacDill AFB, FL

ATTACHMENT 1: ORIGINAL LIST OF EXPEDITED SE QUESTIONS

RT-34 Questions – September 2011. The following introduction and list of questions was provided to site visits in LA on September 26 and 28, 2011.

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Systems Engineering Research Center
Research Topic #34 (RT-34)
Expedited Systems Engineering
Site Visits in LA, Sept 26 and 28, 2011

</div>

RT-34 Problem Statement

The Defense Science Board (DSB) Task Force on the Fulfillment of Urgent Operational Needs (July 2009) identified more than 20 rapid-reaction programs and organizations addressing DoD urgent warfighter needs. A subsequent DSB study found that urgent needs programs spent more than $50 billion between 2005-2009, and that urgent needs should be considered a critical, ongoing DoD institutional capability. In other words, "urgent" is becoming more "normal." In March 2011, the GAO report, "DoD's Urgent Needs Processes Need a More Comprehensive Approach and Evaluation for Potential Consolidation," found that DoD has taken steps to improve fulfillment of urgent needs, but it needs a common approach for addressing urgent needs. The GAO report refers to at least 31 entities that manage urgent needs and expedite the solutions to address them.

This SERC project will examine expedited systems engineering as applied to rapid capability and urgent needs as developed in response to changing threats. Lifecycle of urgent needs programs is driven by "time to market" as opposed to complete satisfaction of static requirements, with delivery expected in days/months versus years/decades. The processes and practices applied to urgent needs must add value and not require an excessive bureaucratic oversight to implement, while at the same time address, understand, and manage risk such that programs can understand better where to include, truncate, or eliminate systems engineering (SE) practices and processes. The hypothesis is that by defining, identifying, testing, and ultimately implementing expedited SE processes and practices, capability that results from urgent needs may be more effective, efficient, and longer lasting in the field. Potential second order effects are that expedited SE as applied to urgent needs could streamline specific future SE practices, as urgent becomes "normal," and findings could eventually improve SE processes for traditional programs as well.

The purpose of the research is to explore and develop a scalable expedited SE framework for hybrid programs, i.e., those utilizing rapid acquisition procurement but with the intent to have a more traditional lifecycle for deployment, maintainability, reliability, adaptability and sustainment. The framework will examine scaling of SE activities in response to different development constraints, such as reduced development time.

RT-34 is a 9-month research task, from September 1, 2011 – May 31, 2012.

> Phase 1: Short planning phase to identify organizations practicing expedited systems engineering, including visiting selected organizations and incorporating input from the SERC Research Council.
> Phase 2: Analyze current state of the art in expedited systems engineering within DoD and commercial sector, developing a framework for scaling SE activities in response to different development constraints, such as reduced development time.
> Phase 3: Prepare a plan for validating the framework on a DoD acquisition program.
> Phase 4 (Future, Separate Funding): Execute the plan from Phase 3, with research to analyze the framework in action and iterate it based on observations and results as applied to a real program.

Site Visits to Aerospace Corporation Concept Design Center & Industry Innovation Lab

Context: Both participated in a previous research paper [Jo Ann Lane et al] on "Critical Success Factors for Rapid, Innovative Solutions," which posed a series of questions on scope, processes, methods, product, tools, people, work space, and key success factors. The paper concluded that successful innovative organizations share certain characteristics:

- Driven by business value
- Take calculated risks
- Follow concurrent engineering practices
- Look for solution patterns that can be re-used
- Proactive management and small agile teams
- Provide culture and environment that supports innovation

RT-34 examines the **systems engineering side of rapid development**.

RT-34 Questions (as of 9/26/11)

1. What systems engineering methods, processes, and tools do you use
   a. What is considered "standard" in your organization
   b. If processes are tailored, which ones are tailorable and why; how do you capture this knowledge
   c. What rationale is used to follow a standard process or not
   d. What is the role of the project manager, chief engineer, chief architect, senior leadership, customer
   e. What level of risk is acceptable and how do you determine
   f. What level of documentation do you use and why
   g. What types of meetings do you hold, who attends, who makes decisions, and why
   h. How replicable / transferable are your processes from one project to another and why
2. Scope
   a. How long is the lifecycle of the product
   b. How many units are you supporting
   c. What different MPTs do you employ based on scope
3. Team
   a. What types of teams do you use (e.g., domain, functional, IPT, etc)
   b. How do you select the team
   c. Who selects the team members and why
   d. What skill mixes are the best
   e. How homogeneous (or not) are the skills, people, and personalities
   f. How do you bring in the government sponsor
   g. How do you bring in the user perspective
   h. How do you manage people and teams that are not co-located
   i. How do you network across these boundaries
   j. How do you handle round-the-clock work and burnout, what is the maximum timeframe that people can withstand the stress (role of stress)
4. Decision Analysis
   a. How are systems engineering decisions made
   b. Who makes the decisions
   c. At what level are decisions made
   d. Who is empowered, how do they know it, how are they supported
   e. Is there a chain of command and how is it used
   f. How do you know when and where to take risks
   g. To what extent are these decisions documented, formalized, communicated
   h. How do you prepare for decisions
   i. How quickly do you need to make decisions
   j. How is decision making in the critical path
5. Product Use
   a. How do you translate prototypes to operational use
6. Scalability
   a. How are your responses above dependent on size of the project (scope, cost, timeline, risk, # of people)
   b. What systems engineering tasks are tailorable or scalable?
7. Collaboration and Communication
   a. What role does collaboration play…in general, in management, in team building, in problem solving, in systems engineering processes, in communication, in knowledge transfer
   b. How do you facilitate collaboration (internal, external)
8. What collaborative tools do you use, which are most effective in which situation and why

ATTACHMENT 2: FINAL LIST OF EXPEDITED SE QUESTIONS

RT-34 Questions (as of 10/10/2011). The following was provided to site visits conducted after October 10, 2011.

Systems Engineering Research Center (SERC)
Research Topic 34 (RT-34)
Expedited Systems Engineering
Site Visits: September 2011 – April 2012

RT-34 Problem Statement

The Defense Science Board (DSB) Task Force on the Fulfillment of Urgent Operational Needs (July 2009) identified more than 20 rapid-reaction programs and organizations addressing DoD urgent warfighter needs. A subsequent DSB study found that urgent needs programs spent more than $50 billion between 2005-2009, and that urgent needs should be considered a critical, ongoing DoD institutional capability. In other words, "urgent" is becoming more "normal." In March 2011, the GAO report, "DoD's Urgent Needs Processes Need a More Comprehensive Approach and Evaluation for Potential Consolidation," found that DoD has taken steps to improve fulfillment of urgent needs, but it needs a common approach for addressing urgent needs. This 2011 GAO report documents at least 31 entities that manage urgent needs and expedite the solutions to address them. The Systems Engineering Research Center (SERC), a DoD University Affiliated Research Center (UARC), has been funded by the Air Force (SAF/AQR) to conduct research exploring this problem.

The SERC project on Expedited Systems Engineering (SE) will examine expedited systems engineering as applied to rapid capability and urgent needs as developed in response to changing threats. Lifecycle of urgent needs programs is driven by "time to market" as opposed to complete satisfaction of static requirements, with delivery expected in days/months versus years/decades. The successful techniques seen in rapid prototyping must scale to larger, more complex, and supportable weapon systems. The engineering processes and practices applied to urgent needs must innovate conceptual solutions, quickly prune the design space, and choose good designs that can delivery warfighting capability. The hypothesis is that by defining, identifying, testing, and ultimately implementing expedited SE processes and practices, capability that results from urgent needs may be more effective, efficient, and longer lasting in the field. Potential second order effects are that expedited SE as applied to urgent needs could streamline specific future SE practices, as urgent becomes "normal," and findings could eventually improve SE processes for traditional programs that want to operate more rapidly.

The purpose of the research is to explore and develop a scalable expedited SE framework for hybrid programs, i.e., those exploiting rapid development, but with the intent to have traditional lifecycle considerations for deployment, maintainability, reliability, adaptability and sustainment. Likewise, this new SE framework would be applicable to more traditional acquisition programs with a desire to incorporate scaled rapid development best practices. The focus is on systems <u>*engineering*</u>*, not acquisition processes.*

RT-34 is a 9-month research task, from September 1, 2011 – May 31, 2012.

- Phase 1: Short planning phase to identify organizations practicing expedited systems engineering, including visiting selected organizations and incorporating input from the SERC Research Council.
- Phase 2: Analyze current state of the art in expedited systems engineering within DoD as well as non-DOC and commercial sector, developing a framework for scaling SE activities in response to different development constraints, such as reduced development time.
- Phase 3: Prepare a plan for validating the framework on a DoD acquisition program.

- <u>Phase 4 (Future, Separate Funding):</u> Execute the plan from Phase 3, with research to analyze the framework in action and iterate it based on observations and results as applied to a real program.

<u>Context:</u> A recent research paper [Jo Ann Lane, et al] on "Critical Success Factors for Rapid, Innovative Solutions," posed a series of questions on potential program success factors. That paper concluded that successful innovative organizations share certain characteristics:

- Driven by business value
- Take calculated risks
- Proactive management and small agile teams
- Look for solution patterns that can be re-used
- Follow concurrent engineering practices
- Provide culture and environment that supports innovation.

RT-34 Questions (as of 10/10/2011)

1. **Systems engineering (SE) methods, processes, and tools**
   a. Do you use standard/ formal SE processes in your rapid development organizations? Which ones?
   b. Are SE processes tailored for each program or product. If so, which ones can be highly tailorable and why
   c. How are SE methods, processes and tools different based on project scale/ scope
   d. What level of risk is acceptable, how do you determine that, and how do you systemically address it at all levels
   e. What is the formality of engineering documentation
   f. How replicable / transferable are your processes from one project or product to another
   g. How do model-based systems engineering approaches support your rapid development
   h. Do you integrate a variety of models/ simulations/ prototypes early in the lifecycle, and if so, how
   i. How would you describe your ability to be innovative in concept refinement
   j. What are best practices for problem domain understanding
   k. How do you manage scope and requirements
   l. What infrastructure (tools, modeling & sim) allows continuously quickening product delivery cycles
   m. Decision Analysis Processes
      i. Who, and at what level, are most engineering decisions made
      ii. Who is empowered, how do they know it, how are they supported
      iii. To what extent are major decisions documented, formalized, communicated
      iv. How do you prepare for major decisions
      v. What role does decision making play in the critical path

2. **People/Team/Collaboration**
   a. What types of teams do you use (e.g., domain, functional, IPT, etc)
   b. What are the primary leadership roles for an expedited project or for the best projects that run the most efficiently (program or project manager, chief engineer, chief architect, etc)
   c. How do you select/ design the team
   d. What are the primary skills you seek for the team
   e. How do you effectively incorporate/involve the end user
   f. How do you effectively and continuously incorporate the user perspective
   g. How do you manage and network people and teams that are not co-located
   h. What role does collaboration play… in management, in team building, in problem solving, in SE processes, and in geographically distributed teams
   i. How do you facilitate improved collaboration (internal, external)
   j. What collaborative tools or processes do you use
   k. What types of meetings do you hold, who attends, who makes decisions, and why
   l. How do you manage urgent project tempos and its personnel effects (stress, work hours, burnout)
   m. How do you reduce complexity of the SE process

3. **Architecture / Product**
   a. How do you translate prototypes to operational use
   b. How long is the intended operational lifecycle of the product
   c. How many units are you producing/fielding
   d. How does your rapid development schedule drive architectural/ design choices
   e. How does reuse, modification of existing systems, or using product lines drive reduced schedules
   f. How does the level of complexity effect the product architecture

4. **Scalability – How are your responses dependent on size of the project (scope, cost, timeline, risk, number of people)**

Input

Input is welcome on this research, in the form of answers to these questions (from individuals or programs) as well as ideas for DoD acquisition programs (Phase 3 and future Phase 4 funding) that could serve as testbeds for the expedited framework.

RT-34 Points of Contact

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Systems Engineering Research Center (SERC)

www.SERCuarc.org

The Systems Engineering Research Center (SERC) is a University Affiliated Research Center (UARC), competitively awarded by the U.S. Department of Defense to Stevens Institute of Technology in 2008. The SERC leverages the research and expertise of senior lead researchers from over 20 collaborator universities and not-for-profit research organizations throughout the United States, with more than 300 researchers working on over 30 tasks over the past 3 years. SERC researchers have worked with a wide variety of domains and industries, and so are able to bring views and ideas from beyond the traditional defense industrial base. The SERC is sponsored by ASD(R&E) and includes strategic sponsors such as the Defense Acquisition University, the U.S. Army, and the U.S. Air Force. Through its collaborative research concept, the SERC embodies the potential to radically improve the application of systems engineering to the successful development, integration, testing and sustainability of complex systems, services and enterprises. The vision is to be the networked national resource to further systems research and its impact on issues of national and global significance.

APPENDIX B: DATA ANALYSIS

B.1 ANALYSIS METHODOLOGY

Using the interview notes, a qualitative analysis was performed using ATLAS.ti™ software in an effort to further explore the data for hidden connections and emergent trends. Full, transcribed interview notes, from 22 of the 25 site visits were assigned to an ATLAS.ti™ hermeneutic unit.   As described in Appendix A, target of opportunity and shorter informal discussions at conferences afforded great openings for data gathering, but this analysis described below was limited to full site visits. Using the 11 common expedited practices (Chapter 2) derived through the site visit discussion process as codes, each document was coded appropriately against key words and phrases. The codes were organized into three families of (1) System/Product, (2) Process and Tools, and (3) People and Organization/Governance. Finally, an analysis was performed to build theory regarding the relationships between the common practices and derive conjecture regarding which practices may be more prevalent across different rapid organizations and domains.

B.2 DATA ANALYSIS RESULTS

While the 22 sampled organizations in the data analysis create different products and use different processes, several common and noteworthy themes emerged from the data. During the qualitative software analysis, the 11 practices discussed previously were coded a total of 310 times against the transcribed interview notes. Figure B-1 shows the number of times each specific practice was materially mentioned or cited as a significant or important business practice in the discussion notes.
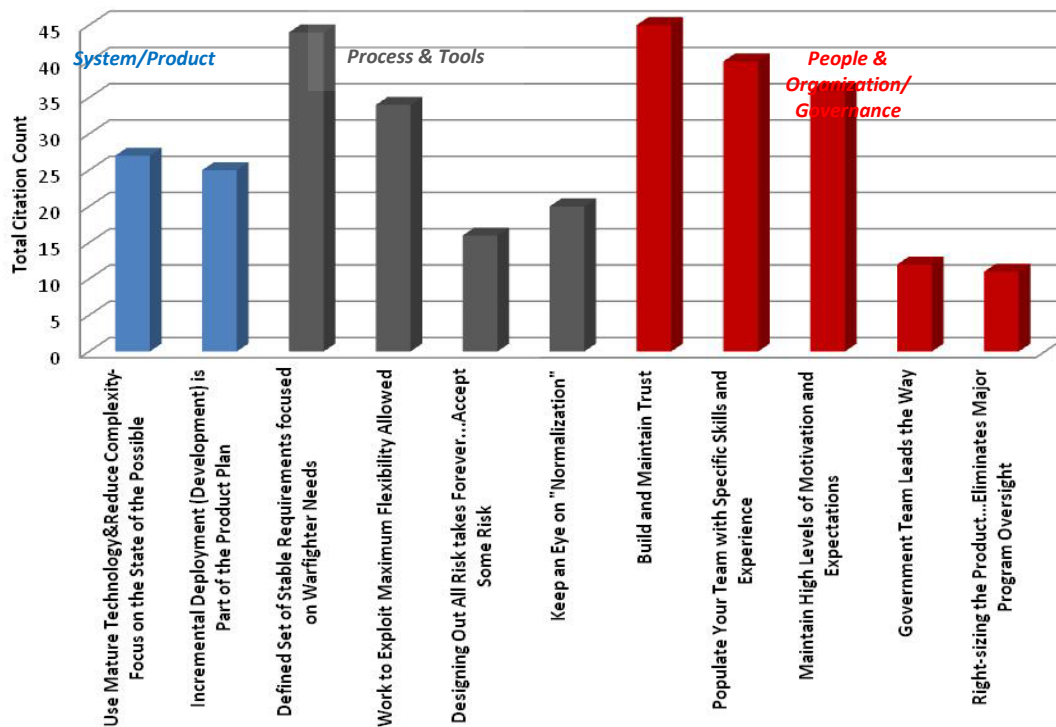

Figure B-1: Total Practice Citation Counts from Sampled Site Visit Data

The data presented in Figure B-1 shows a dominant trend of the top five most common occurring practices of rapid organizations, based solely upon the initial qualitative coding analysis. These five of the 11 total practices identified comprised more than two-thirds (64.2%) of the total citations made during the analysis, with 199 out of 310 total codes, and three of the top five originating in the People and Organization/Governance domain.   See Table B-1.

Table B-1: Top 5 Practices as Mentioned by Total Citation

	Top 5 Practices		
	Practice	*Domain*	*Citations*
1.	Build and Maintain Trust	People & Organization/Governance	45
2.	Defined Set of Stable Requirements focused on Warfighter Needs	Process & Tools	44
3.	Populate Your Team with Specific Skills and Experience	People & Organization/Governance	40
4.	Maintain High Levels of Motivation and Expectations	People & Organization/Governance	36
5.	Work to Exploit Maximum Flexibility Allowed	Process & Tools	34

Examining the number of citations does have some limitations, as the database contained transcribed hand-written notes from each discussion. These limitations include the following: organizations or individuals may use different words to describe the same thing; the same word or collection of words may be heard multiple times by the researcher and thus not written down any more (because that thought was "captured" already); the researcher could write down his or her own interpretation of a word or concept.

A limitation of this approach is that the number of total citations could be influenced by one organization citing one area multiple times. To explore this bias, a second analysis was conducted to examine citations per organization.

The coding of practices to interview data did not result in every organization receiving a corresponding citation for each of the 11 practices. While many of the practices were noted in almost all the organizations, several practices were only prevalent in a small majority of organizations, and some organizations were noted as emphasizing or mentioning a specific practice multiple times, resulting in multiple codes against that practice. For comparison, Figure B-2 shows the total number of organizations citing each practice at least once.
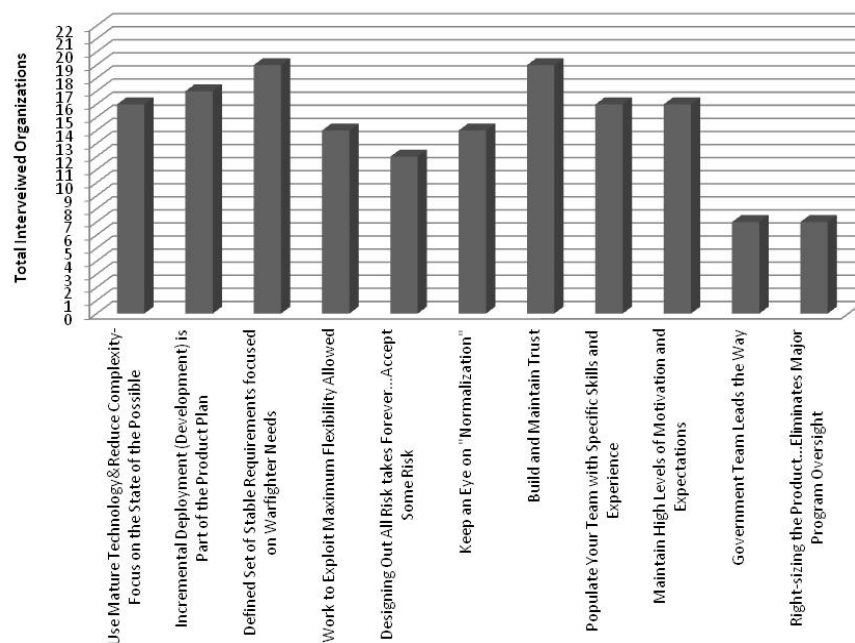
Figure B-2: Number of Organizations Citing each Practice at least once

To further examine the occurrence of practices by each organization, the average occurrence of each practice across all organizations was examined. The two practices with the highest average occurrence (defined as the average time each organization was coded against that practice) are Build <u>and Maintain Trust</u> and <u>Defined Set of Stable Requirements focused on Warfighter Needs</u>; as expected based upon the top five occurring practices presented above, occurring on average twice in each organization. For contrast, Figure B.3 shows the average number of times each practice was coded across all organizations and the maximum time each practice occurred in any organization.
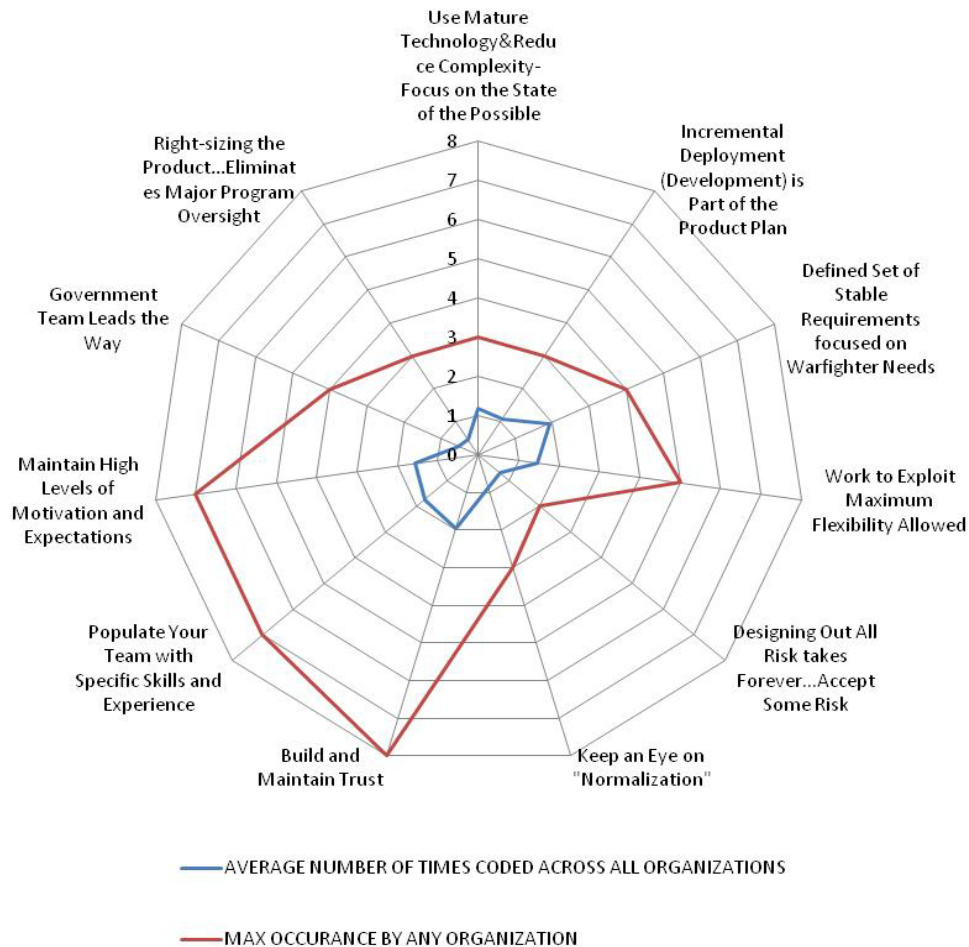
Figure B-3: Average and Maximum Occurrence of Practices by any One Organization

Further analysis was done to examine co-occurrences between practices. Co-occurrence is a tool to examine where potential relationships or interdependencies exist in an effort to discover which principles may relate to one another. In the context of the analysis, practices that were coded to the same document within the corpus of text (semantic proximity) generate a co-occurrence. For example, if a segment of the transcribed notes from an interview was coded to the practice "Build and Maintain Trust" within the document, and then another portion of the document was coded with "Work to Exploit Maximum Flexibility Allowed"; a co-occurrence was generated between the two practices. The raw co-occurrences between practices were then normalized by the total number of co-occurrences. The results in Table B.2 show the highest probability of co-occurrence in within the context of the transcribed documents between the practice of "Build and Maintain Trust" and two other practices: "Defined Set of Stable Requirements focused on Warfighter Needs" and "Populate Your Team with Specific Skills and Experience."

Table B-2: Co-occurrence Matrix

		SYSTEM/ PRODUCT		PROCESS & TOOLS				PEOPLE & ORGANIZATION/GOVERNANCE				
		Use Mature Technology&Reduce Complexity-Focus on the State of the Possible	Incremental Deployment (Development) is Part of the Product Plan	Defined Set of Stable Requirements focused on Warfighter Needs	Work to Exploit Maximum Flexibility Allowed	Designing Out All Risk takes Forever...Accept Some Risk	Keep an Eye on "Normalization"	Build and Maintain Trust	Populate Your Team with Specific Skills and Experience	Maintain High Levels of Motivation and Expectations	Government Team Leads the Way	Right-sizing the Product...Eliminates Major Program Oversight
SYSTEM/ PRODUCT	Use Mature Technology&Reduce Complexity-Focus on the State of the Possible		0.012939	0.012939	0.010166	0.009242	0.009242	0.013863	0.011091	0.010166	0.005545	0.005545
	Incremental Deployment (Development) is Part of the Product Plan	0.012939		0.013863	0.009242	0.010166	0.011091	0.014787	0.012015	0.010166	0.005545	0.005545
PROCESS & TOOLS	Defined Set of Stable Requirements focused on Warfighter Needs	0.012939	0.013863		0.012939	0.010166	0.010166	0.015712	0.013863	0.012939	0.00647	0.00647
	Work to Exploit Maximum Flexibility Allowed	0.010166	0.009242	0.012939		0.008318	0.009242	0.013863	0.012015	0.009242	0.00647	0.004621
	Designing Out All Risk takes Forever...Accept Some Risk	0.009242	0.010166	0.010166	0.008318		0.007394	0.010166	0.008318	0.007394	0.003697	0.003697
	Keep an Eye on "Normalization"	0.009242	0.011091	0.010166	0.009242	0.007394		0.012015	0.009242	0.00647	0.005545	0.002773
PEOPLE & ORGANIZATION/ GOVERNANCE	Build and Maintain Trust	0.013863	0.014787	0.015712	0.013863	0.010166	0.012015		0.015712	0.013863	0.007394	0.004621
	Populate Your Team with Specific Skills and Experience	0.011091	0.012015	0.013863	0.012015	0.008318	0.009242	0.015712		0.012939	0.00647	0.004621
	Maintain High Levels of Motivation and Expectations	0.010166	0.010166	0.012939	0.009242	0.007394	0.00647	0.013863	0.012939		0.005545	0.004621
	Government Team Leads the Way	0.005545	0.005545	0.00647	0.00647	0.003697	0.005545	0.007394	0.00647	0.005545		0.001848
	Right-sizing the Product...Eliminates Major Program Oversight	0.005545	0.005545	0.00647	0.004621	0.003697	0.002773	0.004621	0.004621	0.004621	0.001848	

The results of this co-occurrence matrix are somewhat intuitive. Practices that were coded more often against a transcribed interview tend to show more co-occurrence, as can be seen when comparing the matrix above with the top five most occurring practices. However, the avenues of analysis presented here begin to show some emergent, if not instinctive, correlations. For example, the practices of "Use Mature Technology & Reduce complexity-Focus on the State of the Possible" and "Incremental Deployment (Development) is Part of the Product Plan" both showed strong co-occurrence with "Defined Set of Stable Requirements focused on Warfighter needs."

This correlation may imply that rapid organizations tend to focus requirements directly upon what can be accomplished in the near term while achieving at least some sort of solution to the problem, with the intent of upgrading later as required—which is arguably a common tenant among smaller, rapid Government acquisition organizations. Furthermore, practices under the People and Organization/Governance family showed the most co-occurrence with other practices.

Combined with the analysis showing three of the five most commonly occurring practices under this same domain (see above), an implication is apparent that the principles that define the people on a team have significant contribution to the overall performance of the effort. In the context of the analysis, if an organization had the right people supporting a program, it appears they are more likely to keep the process in check to get the right system or product delivered.

As described in Chapter 3, the organizations interviewed appeared to focus and operate within four lanes of acquisition. Because the organizations varied widely in size and scope, the final portion of the data analysis focused on examining the importance of each practice to the organizations within the three rapid lanes of acquisition. To determine importance, a standardization scheme was derived to assign a scaled importance factor to each practice with the organizations. Because the 11 practices were the result of emergent trends from the qualitative analysis of the entirety of the interview data, it was assumed that every practice holds at least the minimum importance factor value of 1. The importance of each practice was classified from 1 to 4, based upon how many times the particular practice was coded against an organization, under the assumption that multiple citations of a practice to an organization indicates an increased significance to the hallmarks of that specific organization. The standardized importance factor criteria are summarized below in Table B.3.

Table B-3: Practice Count Importance Factor

Importance Factor Value	Criteria	Definition
1	0 Codes	Low importance
2	1 Code	Important
3	2 Codes	Very Important
4	>2 Codes	Essential

Using the standardized importance factors, the organizations were separated into domains by lanes of acquisition, and the total number of citations for each practice was standardized. The standardized importance values were then averaged for each practice. Two of the organizations were classified as both Lab Demo/Ops Prototype and Rapid Platform Engineering based on their activity. Resultantly, three plots were produced to show the average perceived importance of each practice for the organizations with each of the three lanes of acquisition: Rapid Integrated Solutions, Rapid Platform Engineering and Lab demo/Ops Prototype.

The plots are shown in Figure B.4. Note that the lanes of acquisition later were iterated to 4 lanes (versus 3 as shown in the figure), but the ATLAS.ti™ analysis was conducted prior to this point.

INTEGRATED SOLUTION
AVERAGE PERCEIVED IMPORTANCE

PLATFORM ENGINEERING
AVERAGE PERCEIVED IMPORTANCE

LAB DEMO / OPERATIONAL PROTOTYPE
AVERAGE PERCEIVED IMPORTANCE
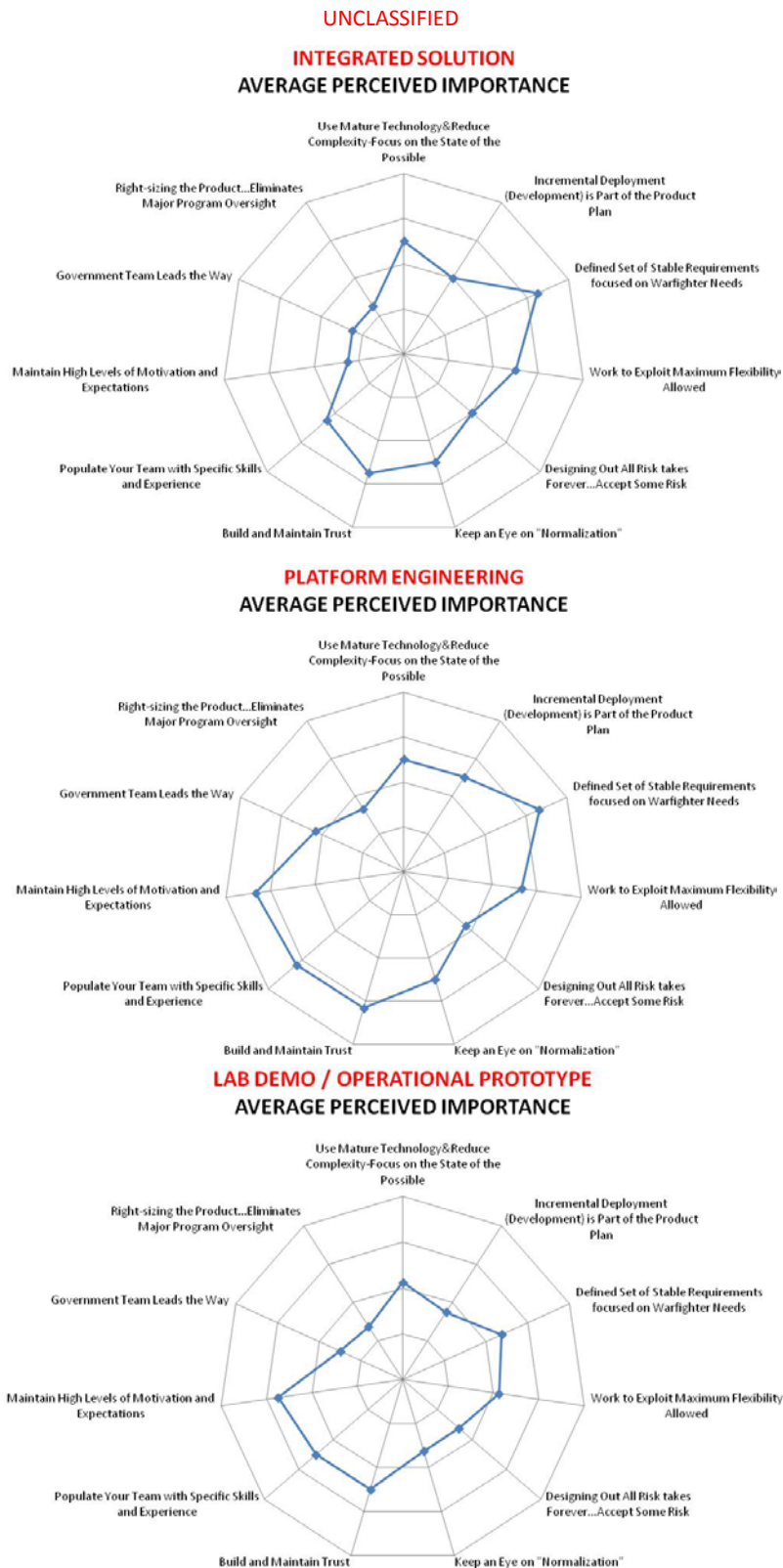
Figure B-4: Average Perceived Importance (Standardized) by Lanes of Acquisition

For comparison, all three importance plots are presented together to show differences and similarities between the lanes of acquisition in Figure B-5.
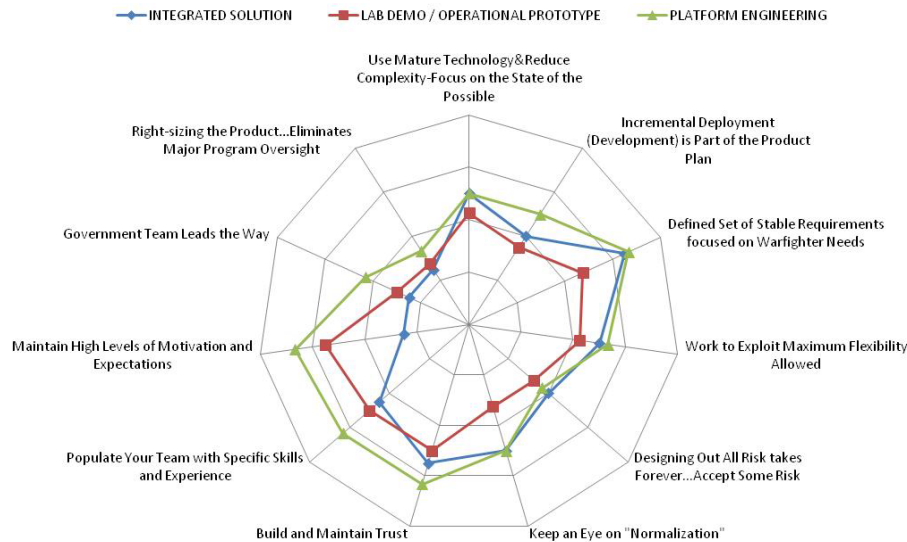
Figure B-5: Average Perceived Importance of Practices by Domain

Some of the results shown above could be expected. For example, organizations classified as Lab Demo/Operational Prototype show a lower importance on the practice "Keep an Eye on 'Normalization'" as compared to those organizations executing Platform Engineering or integrated Solutions, which should be expected. All of the organizations appeared to value practices relating to team skills and experience and trust relationships within the team, harkening back to the previous conjecture that the right people and team environment can significantly contribute to the tenants that drive Rapid. Finally, the perceived importance plots seem to indicate a fairly common shape, showing relative correlation between rapid organizations across three distinct lanes of acquisition. One exception is regarding the practice of "Maintain High Levels of Motivation and Expectations" which was observed as less important in data from organizations in the Integrated Solution lane. While potential conclusions are presented elsewhere, data analysis shows that a set of common practices did emerge among rapid organizations, with emphasis on people, requirements, mature technology and incremental deployment and development surfacing as commonly occurring and increasingly important across the spectrum of organizations sampled.

C.1 INTRODUCTION

It became clear during the early execution of this Research Task, that many of the other SERC RTs may generally improve Systems Engineering within any program, with a side effect that programs may be more effective, efficient, and ideally quicker. This Appendix examines the relationships between RT-34 and a number of other SERC RTs. RT-34 is the first SERC RT to look at the "research program" level of other SERC research to see how to best leverage multiple investments into an overall category of "expedited development." The data on the other RTs was gathered from publicly available descriptions and research reports posted on the SERC website at: www.SERCuarc.org. Some RTs may have more accomplishments than described herein, but the point was to take a consistent view across what was available. This exercise provides RT-34 with additional support for our findings (extracted through interviews), and also can put other RT recommendations, observations and findings in context to rapid acquisition for urgent needs. Table C-1 below shows the RTs examined.

Table C-1: SERC RTs Selected for Comparison

SERC Research Task	Description of the Research
MPT (Methods, Processes, and Tools)	Evaluation of Systems Engineering MPTs
TO-001	Early Identification of SE Related Program Risks
RT-10	Systems Engineering Transformation
RT-18	Value of Flexibility
RT-19	Building Education and Workforce Capacity in Systems Engineering
RT-24	Integration of Modeling and Simulation, Software Design, and DoDAF
RT-25	Requirements Management for Net-Centric Enterprises
RT-27	System Maturity and Architecture Assessment
RT-30/31	Graphical CONOPS
RT-35	Kanban in Systems Engineering

In particular, Graphical CONOPS, valuing flexibility, and methods for requirements engineering were all found to be useful in the concept and requirements development phase of systems engineering. The requirements engineering research task specifically looked at large IT mergers, though some of the principles may be useful for overall systems engineering. Valuing flexibility looks at ways to quantitatively measure the value of engineering flexibility into systems, which is useful for trade-off analysis. System Readiness Levels looked at ways of measuring the maturity of existing systems, which is useful when using pre-existing systems and technologies to speed the development of a new system. Kanban scheduling proposed a method of scheduling and management that enabled a team to have deliverable and testable products as quickly as possible. Integrated modeling focused on methods of picking the appropriate acquisition framework for a project, which may help tailoring and speeding up acquisition by enabling teams to find the quickest and most effective acquisition framework for their project. Workforce development looked at ways to speed the education of systems engineers, as well as ways to spark student interest in systems engineering. This could be used to "build" systems engineers with the necessary skills and backgrounds for any project, as well as developing trust between engineers. This could also go the other way, as expedited SE can provide a method for students to see an entire acquisition process, where normally they would only be able to see a small milestone due to the length of DoD acquisition processes. Workforce development recommendations are further explored in Chapter 5. Systems Engineering Transformation proposed eight areas of systems engineering that have since evolved, many of which are addressed in other research topics that were analyzed for RT-34.

Figure C-1 puts the RT-34 findings into perspective with the selected RTs that apply to expedited development. The rest of this appendix takes each RT examined and includes a "description" and the "application to RT-34."
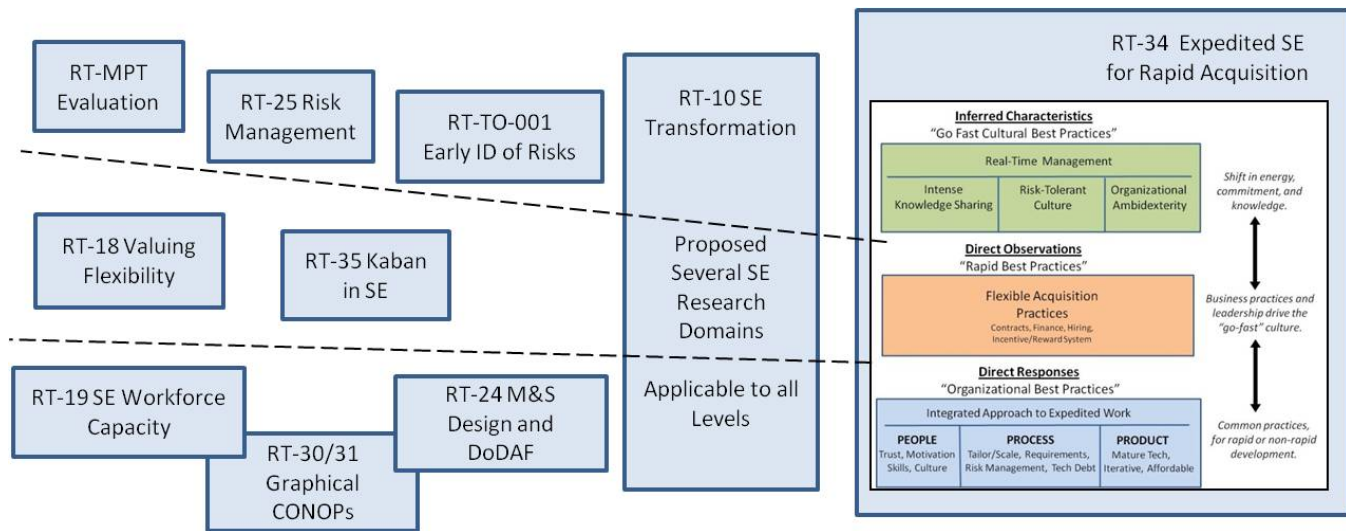
Figure C-1: SERC RT Relationship to RT-34 Framework

C.2 SERC RESEARCH TASK – MPT (METHODS, PROCESSES, AND TOOLS)

C.2.1 DESCRIPTION: EVALUATION OF SYSTEMS ENGINEERING MPTS

Overview: The purpose of RT-MPT is to address SE shortfalls, specifically in quick response, network-enabled and emergent project areas. Phase I was focused on developing useful MPTs in those areas, and identifying gaps where no useful MPTs could be found for future research. Phase II was focused on gathering further information on those MPTs and developing a taxonomy for them, investigating micro-process modeling techniques to support the definition and evaluation of the MPTs, and to provide an implementation guidance on the MPTs.

Phase I: For Phase I, the research team conducted surveys of industry programs, held interviews and did a literature search to come up with three MPTs to increase effectiveness in the SE environments stated above.

1. Scrum (lightweight project management methodology, only addresses project management and planning)
2. Rapid Prototyping
3. Continuous Integration

Three gaps were also identified where no or few useful MPTs could be found.
1. Decision management
2. Stakeholder requirements definition
3. Sustainment

Further research was deemed necessary in another three areas.
1. Mitigating environmental constraints
2. Refining definition of current state of SE practice
3. Accelerating MPT adoption

Finally, four key challenges to effective SE were observed and defined.
1. Requirements- Changing and emergent requirements and priorities
2. Stakeholders- Obtaining useful stakeholder input and dealing with conflicting stakeholder requirements
3. Sustainment- Conflicts between developing new capabilities and supporting current systems
4. Integration- Integrating independently evolving components into a larger, interoperable system

Phase II: Phase II had three main focuses.
1. Gather information on MPTs developed in Phase I and develop a taxonomy for them
2. Investigate micro-process modeling techniques to support definition and evaluation of MPTs
3. Provide implementation guidance on MPTs

Towards this end, follow-up interviews were conducted, and research was done to investigate the MPTs from Phase I.

The taxonomy developed was based on previous information, augmented by interviews. It is used to describe the three recommended MPTs, and was shown to be useful when validating and implementing the MPTs.

Micro-process modeling was used to develop models of Scrum. Analyses were successfully performed with models, validating the use of such modeling techniques.

Implementation guidance was developed using the taxonomy, as well as a generic understanding of the environments the MPTs were to be implemented in.

C.2.2 APPLICATION TO RT-34: RT-MPT

As this research defined three different MPTs useful for rapid response programs, each will be analyzed separately.

Where: Scrum is mainly applicable to requirements development under the process aspect of level 1 and the people aspect of level 1, namely with respect to having a team one can trust. It can also apply to the real-time management aspect of level 3. One focus in Scrum is to determine the project requirements collaboratively with all stakeholders, and then break them down into independent features. Also, the project manager only addresses management and planning, leaving the technical processes in the hands of his team, which inherently involves a certain amount of trust. This management style can then also be applied to real-time management strategies.

Rapid prototyping doesn't fit exactly into the expedited SE framework. It fits most closely to the risk-focused culture aspect of Level 2, as the purpose of rapid prototyping is to create a mock-up of a full system to determine and mitigate possible sources of risk.

Continuous integration fits closest to the intense knowledge sharing aspect of level 2. It allows complete project visibility from everyone on the team, and ensures that all parts work together at every step of the way, minimizing the possibility of wasted time due to a redesign caused by incompatible parts.

How: Scrum is a method that should be tested on smaller projects before applied to a full scale, high priority task. As far as implementing it, one needs to find a project manager that trusts his team enough to let them do the majority of a project without much management.

For rapid prototyping, the team must be skilled at creating minimal representations of the system they're developing and be able to do it accurately and in a short time frame in order to keep the process expedited. Also,

being able to look at a crude representation of the full system and see where improvements need to be made is invaluable.

Though primarily for software development, continuous integration can be utilized for mechanical systems as well, though this may necessitate that integration is done slightly less frequently due to the more complicated process of mechanical integration. Setting aside time for integration is a managerial scheduling task.

When: The decision to use scrum needs to be made well before a project starts, and then it must be followed through the entire lifecycle of the project. The trust inherent in this managerial system, however, needs to be developed over time.

The timeframe for rapid prototyping can change from project to project depending on the amount of work to be done, but in general it should be started early to determine any errors or omissions with regards to the system requirements, and to ensure that the system is fully functional.

Continuous integration can be started as soon as all team members have some form of deliverable from their work. Similar to rapid prototyping, this should be started early and done consistently to ensure the team is staying on task and is developing parts that will work together seamlessly towards the fulfillment of the requirements.

C.3 SERC RESEARCH TASK – TO-001

C.3.1 DESCRIPTION: EARLY IDENTIFICATION OF SE RELATED PROGRAM RISKS

Overview: The DoD needs effective Systems Engineering programs in order to succeed. These systems must stay on budget and on schedule in order to be effective. As such, a method must be devised in order to determine any risks to achieving effective Systems Engineering and ensure that the system will meet budget and scheduling requirements.

These risks are generally a result of:

- Inadequate program funding
- Misguided contract provisions (not addressing key program parameter risks)
- Leaving difficult tasks for later in order to show early progress

Unaddressed risks typically lead to overrunning budget and time constraints.

Current Practices: Current methods for examining systems often neglect to support evidence about how well the elements of a system will perform, how expensive they will be, or how compatible their underlying assumptions are. They tend to stick to best-case scenarios without examining if the system could handle "rainy-day" scenarios, be buildable within given budget and time constrains, or give positive return on investments for stakeholders.

Proposed System: Through several literature reviews, Critical Success Factors (CSFs) were identified that must be met in order for a system to avoid risk and be effective. 23 CSFs were identified, relating both to the performance of the system and the competency of the people involved. These CSFs were organized into five overall goals:

- Concurrent definition of system requirements & solutions
- System life-cycle organization, planning & staffing
- Technology maturing & architecting
- Evidence-based progress monitoring & commitment reviews

- Professional and interpersonal skills

In order to determine if these goals and CSFs were met, a series of 81 questions was devised. For each system that was being analyzed, the questions were categorized based on the relative impact a negative answer would have on the system, measured by a percent overrun of budget and time constraints. They were separated into critical (40-100% overrun), significant (20-40%), moderate (2-20%), and little to no impact (0-2%). For each question, evidence is provided in the form of prototypes, models, simulations, etc. The strength of the evidence is based on the evaluation of this evidence by impartial experts. The strength of the answer is then used to determine the risk probability which, when multiplied by the risk impact gives the total risk exposure for that area. Each CSF is then given a risk rating equal to the highest risk rating among the questions relating to it.

C.3.2 APPLICATION TO RT-34: RT-TO-001

This task order was concerned with SE risks that cause projects to go over the scheduled time or allotted budget. This is different from the risk in principle 8 of the expedited systems engineering framework, which is primarily the risk associated with a system after it has been deployed.

Where: The research from Task Order 001 relates most closely to the risk-focused culture aspect of level 2. It deals primarily with finding methods of mitigating risk associated with systems engineering practices. The methods used to accomplish this, however, fit more into the requirements development phase of a project, under the process aspect of level 1, as well as maintaining a small (but not too small) budget which fits under the product aspect of level 1.

How: Using the MPTs defined by this Task Order it is possible to find where the risk of failure is in a given project. If people are aware of where the risk is and how much of a threat it is to the project running over time or budget, they can take measures to mitigate and eliminate this risk before it causes lasting problems. With success such a large issue with regards to expedited systems engineering, the ability to at least ensure that a project won't fail outright is a step towards guaranteeing the overall success of the project.

When: The MPTs for identifying risk can be used at any point in a project, but would be most effective if used in the early planning stages, before budgets or schedules are set in stone, so that they may be changed in order to mitigate risk. Areas of risk should then also be monitored throughout the life cycle of the program so that if a problem arises, it is recognized sooner rather than later and can be dealt with before its effects begin to inflate. Several follow-up, total system risk assessments may also be conducive to risk identification and mitigation.

C.4 SERC RESEARCH TASK – RT-10

C.4.1. DESCRIPTION: SYSTEMS ENGINEERING TRANSFORMATION

Overview: Current Systems Engineering was developed primarily for the Space Race in the 1960s and 1970s and is deemed to be outdated by current trends in technology and design expectations. Research Task 10 is dedicated to creating a three year road map of research that will transform the Methods, Processes and Tools used in Systems Engineering to be better suited to current needs and make it more agile, integrated, efficient, leveraged, and deployable.

Trends: Several trends were described in current society, each of which was incompatible with standard Systems Engineering and are as follows:

1. More complex Systems of Systems (SoS) as opposed to single, stand-alone systems. This complicates the design process as one must be aware of all social, economic, political, technical, behavioral, or environmental issues involved in order to develop an optimal system.
2. Increased dependence on advanced yet unpredictable SoS makes them a necessity rather than a convenience. Systems, services and users are now all expected to interact and collaborate.
3. Increased customer expectations and competitive demands shorten the lifecycle of services and products.
4. The increased dependency on networked systems increases their value as a target, and their increased interconnectivity increases their vulnerability. This increases the importance of security, especially when dealing with SoS.
5. Decreased occurrence of "brand-new" ideas and designs. Systems must work with more and more legacy systems which may not be suited to their future missions as a result of this future usage being unforeseen at the time of their initial design.
6. The workforce is becoming more interactive and experiential, and more accustomed to change and lack of knowledge of a system.

Domains of Transformation: RT-10 described eight domains that must be researched in order to transform Systems Engineering.

1. Prioritization & Tradeoff Analysis: Rather than creating a 100% solution while mitigating all risk, a tradeoff must be made between budget, usability, security, overall value, and time to completion. Techniques must be researched to analyze prioritization tradeoffs to improve quality of decision making and reduce time to completion.
2. Concept Engineering: Interactive, multimedia environments must be developed to quickly create CONOPS and models in conjunction with multiple stakeholders to speed the design process and allow all involved to get an idea of what the system does, as well as its value.
3. Architecture and Design Analysis: Visualization and analysis tools must be developed to facilitate decision making through specification and design processes. Such tools could help determine how and where a system should be modified while minimizing the impact on design and testing.
4. Design & Test Reuse and Synthesis: A method is needed to categorize and catalog existing designs and technology for reuse. Methods to synthesize existing architectures for use in new designs using these databases must be explored.
5. Active System Characterization: Methods and tools must be developed to facilitate real-time analysis of existing systems to determine their value as well as their usability in future designs.
6. Human-System Integration: Models are needed to determine how humans will interact with the system, as well as the capabilities and limitations of the people designing the system.
7. Agile Process Engineering: Processes must be created to rapidly develop systems that are agile and adaptable to changes in tools and technology, in environments that may not be suited to agile development.
8. Modeling Environment Infrastructure: There must be a way to provide effective communication between the created models and the users of those models, and the design environments.

C.4.2 APPLICATION TO RT-34: RT-10

Due to the fact that the purpose of RT-10 was to create a roadmap for future research, analysis will be done on each of the individual domains stated above. The relationship to RT-34 of these domains when the proposed research on them is complete will be analyzed. Each domain will be referred to by its number in the above summary for convenience.

Where: Domain 6 is the only domain related to the people aspect in level 1 of the expedited SE framework. Being able to determine the capabilities and limitations of the people developing a system could prove useful for picking a

team with the right skills and motivation, and then being able to trust them with working on an expedited project. This could also help in the Organization Ambidexterity aspect of level 2, as it will enable picking people capable of working under several disciplines.

Domain 1 fits into the Process aspect of level 1, as it works under the assumption that some risk is acceptable, and works to create a trade-off between risk, cost, schedule, etc., in order to build a design a quality product rapidly. It is also integrated into the Risk-Focused Culture aspect of level 2, as having people that are accustomed to risk and are comfortable dealing with and mitigating it will be able to use this tool more effectively to speed up a project.

Domain 2 also fits into the process aspect of level 1. Having a method to quickly and reliably come up with the requirements of a system, enables a team to start work on the system faster, and make design changes due to unclear requirements less likely

Domain 3 is most relevant in the product aspect of level 1, as it deals mostly with mature technology and developing methods of finding existing technologies relevant to current design problems.
Domain 7 relates most closely to the Flexible Acquisition Practices of level 3. Being able to tailor acquisition processes, especially in big acquisition, can drastically speed up a project.
Domain 8 fits closest to the process aspect of level 1, specifically with regard to requirements. It ensures that the time spend developing detailed requirements to the satisfaction of the user isn't put to waste by veering away from the proposed design.

Domains 4 and 5 help to facilitate the use of mature technology for the product aspect of level 1. These domains play off each other, as domain 4 seeks to create a database of existing technologies, enabling engineers to search for previously designed components that may solve problems they are facing, and domain 5 seeks to categorize existing systems to fit into the database created by domain 4, as well as defining their capabilities and behaviors to ensure that they are utilized correctly in future systems.

How: Domain 1 can be utilized to determine exactly what will be delivered at the end of the project. After conversations with stakeholders to determine how much risk they're willing to accept, the time frame they need a product in, and their budget, the result of research in this area will be used to quickly identify just how much of the total solution can be reasonably designed with those given resources, and how much value it will give to the stakeholders. Based on that, requirements can be modified until all stakeholders are satisfied with the end result.

Domain 2 is useful for setting the requirements for a project, which can be very conducive for rapid development and deployment. Specifically, the fact that all stakeholders are able to participate in the concept engineering will negate the possibility of designing a product or system that doesn't fit the stakeholder's needs, as they will be involved with every step of development to ensure they are getting what it is they need.

Domain 3 takes some of the risk out of the design process by helping engineers see what parts of a system they can modify with minimal impact on the design. This in turn doesn't necessitate as much testing as if a modification would have an unknown or large impact on a system. This can save the time that would otherwise be spent on extra testing, as well as mitigating some of the risk associated with modifying systems.

Domain 4 can inform engineers what legacy systems and mature technologies are available much easier and faster than may otherwise be possible. Also, if existing systems and products are made more accessible, one may be found to fit a stakeholder's requirements that may not have been found otherwise, saving a substantial amount of time that would have been required to design a system or part that already exists.

Domain 5 offers a method to provide feedback between the virtual and physical domains of a system. The up to date data it provides allows real-time updates of models of the technical systems and of human behavior and system usage of the system being developed, as well as the system doing the developing. These updates can be used to determine the effects of changes made to the system in terms of time, effort, cost and risk, allowing engineers and designers to see the consequences of any modifications they may be considering before they are made, possibly saving precious time and resources.

Domain 6 allows optimization with regards to the human aspect of a system. This domain can be used to model human interactions with the developed system to ensure that it responds in a way suited to fulfilling the system's requirements. This makes it possible to know that a developed system will be fully useable by the warfighter it was developed for.

Domain 7 provides the processes and governance to enable parallel development in the aforementioned domains. The processes developed in this domain function primarily to facilitate the interactions between the other domains, ensuring that they all work cohesively to enable rapid and agile development. This domain paired with domain 8 make up the environment, processes and governance that the other domains will work within.

Domain 8 provides an infrastructure to support all the aforementioned domains, as well as providing an effective interface to users of the system. This provides a means to realize the agile processes in operation. This enables systems engineering to be an integrated, embedded capability in the support of systems throughout their lifecycle.

When: Domains 1 through 3 are all primarily concerned with developing requirements and picking an effective design. As a result, these three modules will be implemented very early in the systems engineering process. Starting with domain 1 to create a set of requirements, these requirements can then be used alongside domain 2 in order to develop a design with models and a full set of CONOPS that satisfies the stakeholders. This can then be used in conjunction with domain 3 in order to pick the optimal design based on analysis done through domain 1.

Domain 6 can be implemented in the earlier phases of design and used throughout the majority of the design process. Creating models that take human interactions with the system into consideration is important when choosing a design, and can then be utilized during the entire design and development process in order to ensure that the system being designed is optimized in its capabilities both from a technical and human aspect.

Domain 5 is relevant in several different systems design and engineering phases, each in unique ways. In the earlier phases of systems design, existing systems that have been analyzed and characterized using the MPTs of domain 5 can be looked at for possible uses in new development. In later phases, after a system has been developed and is being deployed, this system can be characterized for possible use in future systems.

Domain 4, when the proposed system has been completed, can also be used early in the design process to find existing systems that may be implementable with a current systems engineering project.

As a result of domains 7 and 8 primarily dealing with the integration of the above domains and the creation of interfaces, environments and architectures with which to utilize these MPTs, these two remaining domains are utilizable throughout the entire lifecycle of a system, from concept engineering and requirement analysis, through its deployment stage.

C.5 SERC RESEARCH TASK – RT-18

C.5.1 DESCRIPTION: VALUE OF FLEXIBILITY

Overview: Though it is widely accepted that flexibility is a good thing, there is yet a way to measure the value of flexibility, especially with respect to Systems Engineering. This research task is an effort to put a quantitative value on engineering flexibility into systems in various situations, allowing DoD acquisition personnel to make informed decisions on "how much to invest in flexibility."

Definition: The first task is to set a definition for flexibility. Multiple definitions for flexibility, as well as definitions for multiple different kinds of flexibility were analyzed and five categories were extrapolated that were useful in defining flexibility:

- Whether or not the system changes
- How efficient the change is with respect to time and money
- The source of the change with respect to the system (internal, external, requirements based)
- Whether the change was foreseeable or not
- Whether the change happened before or after the system was fielded

Cost: In determining the value of flexibility, the first step was to determine the cost and what were (if any) the tradeoffs of engineering flexibility into the system. It was speculated that adding flexibility would result in a higher expenditure of resources and/or decreases in productivity of the final system. Flexibility was also shown to have rapidly diminishing marginal returns on investment; there was not much more value in a lot of flexibility than there was in a little flexibility.

Benefit: Through analysis of software product line reuse, engineering products that will be adequate for reuse cost 50% more in development and certification, but then reusing those products without modification cost 20% of the cost of redeveloping components. These parts were also shown to be useful in lines of at least three similar products. If the components were modified before reuse, 20%-50% was added to the cost of reuse.

Methods: In mechanical systems, the overall function is achieved via the interactions of several sub systems and components. This makes alterations to one component difficult as any changes in that may make it incompatible with the other components, and as a result, when engineering with flexibility in mind, modular designs should be chosen so that alterations to one subsystem will have less of an impact on the subsystems it interacts with. Initially, any foreseen changes must be integrated into the design, adding versatility and possibility for upgrades and customization. After that, design must begin to compensate for unforeseen changes.

Value: Several methods to quantitatively determine the value of flexibility in design were examined:

- Total Ownership Cost (TOC): The cost to research, develop, acquire, own, operate, and dispose of a system. This takes into account the extra costs associated with designing a flexible system, as well as the savings downstream in reusing the design. Creating a TOC of the same system both with and without flexibility allows one to put a monetary value on the flexibility and provides a way to determine appropriate levels of investment in flexibility.
- Hedge Framework: Takes into account the value of a system's current capabilities as well as its opportunities. In order to do this, the possible opportunities and the possible environments that a system may have value in must be explicit during design and engineering. The approach is to make models of where and when such a system could be valuable. This method is still under development by The University of Virginia.

- Knowledge Value Added + Integrated Risk Management and Real Options: Measures operating performance, cost effectiveness, return on investment, risk, real options, and analytical portfolio optimization. This determines the value based on the return on knowledge and the return on investment of a system, quantifying the value of processes, functions, departments, divisions, and organizations in common units. It is able to highlight efficiencies and inefficiencies and estimate the total value created by adding flexibility.

Due to the fact that RT-18 has to date only completed phase 1 of its proposed plan, phase 1 is all that will be analyzed. This phase specifically focuses on finding MPTs that enable one to place a numerical value on engineering flexibility into a system.

C.5.2 APPLICATION TO RT-34: RT-18

Where: The results of the phase 1 research of RT-18 is relevant in the process aspect of level 2, specifically with regard to requirements and risk accepting, as well as in the risk-focused culture aspect of level 3. Having a numerical value for designing flexibility into a system provides another metric for trade-off analysis between flexibility, risk, cost, etc.

How: In order to first put a number on flexibility in a system, one must use one of the MPTs defined by phase 1 of RT-18. Then, using a tradeoff analysis, possibly the one from RT-10, it must be determined just how much flexibility to engineer into a system in collaboration with the stakeholders. This must take into account the value as well as the cost of flexibility with regards to the particular system being looked at. Perhaps for the system in question, it's vastly more important to have a completed product on time, or within budget, or with more productivity than it is to have flexibility engineered in.

When: At this phase of the research, as it is solely concerned with placing a value on flexibility, the timeframe for its use is limited to the early development stages, namely the creation of requirements and capabilities and perhaps the CONOPS development. The eventual end product of MPTs that enable flexibility to be engineered into a system will be applicable throughout the entire design and development cycle of a system, and possibly into its deployment and reuse.

C.6 SERC RESEARCH TASK – RT-19

C.6.1 DESCRIPTION: BUILDING EDUCATION AND WORKFORCE CAPACITY IN SYSTEMS ENGINEERING

Overview: The goal of RT-19 is to understand the impact of a set of diverse capstone courses on student learning of and career interest in Systems Engineering. Participating students were exposed to real DoD problems, along with differing course designs, structures, materials, and involvement of DoD mentors to assess how these differences affect the student's learning and interest in Systems Engineering.

Methods: The Capstone project was piloted in eight civilian and six military universities. Participating students from these universities were split into groups and given one of four real DoD problems to work on over the course of the 2010-11 academic year. Teams were organized in various ways, the most common being multiple teams working on multiple different design problems.

Most institutions had systems engineering faculty lead and assist with the development of the course, though many also had faculty from various other backgrounds assist as well. 11 of the 14 institutions had faculty from at least three different backgrounds involved with the project. Only one institution had one faculty member involved.

In order to analyze the impact of the capstone project on the student's learning of SE, student interest in SE careers, and student awareness/interest in authentic DoD problems, pre/post surveys and case study analyses were collected, and student blogs were analyzed, as well as custom assessments, designed by the participating faculty. A case study of a Bradley Fighting Vehicle was done by students both before and after their capstone experiences. Using an analytic rubric, the complexity of the student's thinking using systems engineering was measured.

Findings: After the completion of the capstone courses, students were found to be more aware of specific problems faced by the DoD. Student's awareness was most increased with respect energy-related problems, and most decreased with respect to weapons systems. Students were also seen to use SE terminology significantly more.

A survey on student interest in systems engineering careers did not show statistically significant increases in interest in careers in general, or in government and industry. However, for students with no prior SE experience, increases in interest were shown in all areas, with the highest average increase being in industry. Students with prior SE experience showed an increase in interest in SE careers in general and in industry, but decreases in government careers. 80% of students said they would consider a career in systems engineering, but that they would prefer to gain experience in their chosen field first. The students that said they wouldn't consider a career in systems engineering mainly cited their current engineering field as the reason they wouldn't.

The DoD mentors were seen to be most beneficial when communication between mentors and students was frequent and specific, such as for design reviews. Students said the mentors helped them avoid "exploring too many blind alleys." In all but one institution, however, students rated the mentor's usefulness in learning about and applying SE in their courses in the low- to mid-range, as compared with other aspects of the capstone courses.

C.6.2 APPLICATION TO RT-34: RT-19

Where: RT-19 relates very strongly to the people aspect of level 1. Being able to "grow" an engineering team with the right skills, motivation and culture, and the ability to trust them is an enormous asset in expedited engineering. It could also be beneficial in the organization ambidexterity aspect of level 3, as it would be possible to train engineers in multiple areas to broaden their expertise, as well as making them more comfortable working in areas other than what they specify in.

How: Through the MPTs formed through RT-19, it may be possible to pick students from different backgrounds, with different experiences and skill sets, and form them into systems engineers with a desired set of skills or a particular desired background. If the students are picked carefully or the courses are constructed in a specific way, it may be possible to custom order and grow an engineer with exactly the right background, skills, experiences, etc., that one needs for a particular task.

When: As this research task was concerned with the impact of different teaching methods for systems engineering on students, all of it must be done well before any systems engineering design tasks are started. As such, a modicum of foresight is required with regards to what problems may arise when the next "batch" of systems engineers has finished their courses and matured. This, an incredibly varied workforce will need to be trained in order to have the right person for the job, no matter what that job may be.

C.7 SERC RESEARCH TASK – RT-24

C.7.1 DESCRIPTION: INTEGRATION OF MODELING AND SIMULATION, SOFTWARE DESIGN, AND DODAF

Overview: There is little information transfer or model reuse among architecture compliance, simulation, and software engineering models, generally resulting in unnecessary redundancy, models that are out of sync, and a loss of domain knowledge and information. This is a direct result of differences in methods, tools and data formats between the three areas. This Research Task investigates ways to integrate these areas.

Different techniques for specification of software requirements (SysML), simulation models (Arena) and enterprise architecture (BPMN) were compared and the different concepts of each language were related to each other using DoDAF 2.0 as a framework. A prototype converter between BPMN 2.0 XML and Arena was developed that allowed users to reuse BPMN models for event simulation.

Motivation: Requirements management for software-intensive systems are typically disconnected from the actual codebases and architectural tools used to create the models and representations of the system architecture, as well as the simulation tools used to evaluate the architecture. As a result, developers and architects are required to manually link the requirements to the data in other tools, and need to do this repeatedly as significant changes occur in either environment.

Project Phases: Project proceeded in three stages:

1. Focus on methods and techniques for system and software modeling; created mapping between different modeling languages
2. Focus on modeling views needed for system documentation and useful for system design; determine usefulness of DoDAF for software engineering; map different model types over DoDAF 2.0; determine extent formal models cover DoDAF 2.0
3. Prototype findings from (1) and (2); develop model convertor; Transfer requirements models from news use case to executable workflow model

Findings: A set of recommendations were developed through the course of the project:

1. Clearly define the key vocabulary, including capabilities, activities, resources and performers
   a. Capabilities- desired effects of system
   b. Activity- action that transforms input into desired output
   c. Resources- inputs/outputs to activities
   d. Performers- actors that execute activities
2. Understand that not all perspectives of DoDAF 2.0 framework are useful for software based projects. Useful perspectives include CV-6, DIV-1, OV-6c, and SV-10a
3. Process models should be developed early in order to check completeness of architectural scope and dynamic behavior of intended system
4. Simulation models should be integrated into the software design process, as they allow developers to estimate system performance and are affordable to integrate

Proper use of these recommendations helped facilitate the transition from requirements engineering into simulation and implementation.

C.7.2 APPLICATION TO RT-34: RT-24

As much of the RT-34 research was done on physical systems engineering, RT-24 could help transition into software systems development by providing the basis of an expedited framework.

Where: The recommendations concerned with modeling as well as, to a lesser extent, the recommendation to define key vocabulary relate to the process aspect of level 1 in the expedited framework, specifically with respect to the requirements portion of systems engineering. Recommendations as to what acquisition frameworks to use in particular instances could be useful in the flexible acquisition practices aspect of level 3 to ensure that only useful acquisition techniques are being used.

How: The implementation of these recommendations starts at the project manager level. He should ensure that the key vocabulary is defined and the useful DoDAF frameworks are chosen for integration with the project. The development of models is more so a function of the design team than of the manager, though he should be aware of the process and its value. Development of these models should begin shortly after the requirements are set—if not sooner—to ensure maximum benefit is seen from them.

When: The recommendations would be most useful in the early stages of a project. The first two should be among the first things done as they set the foundation for the project to come, and are important to planning out the stages and methods of the development of the project. The third recommendation explicitly states it should be completed early, specifically in parallel with or shortly after the requirements development. The same goes for the fourth recommendation, and all of these recommendations should be repeated with any significant changes to the project.

C.8 SERC RESEARCH TASK – RT-25

C.8.1 DESCRIPTION: REQUIREMENTS MANAGEMENT FOR NET-CENTRIC ENTERPRISES

Overview: A Net-Centric Enterprise is a number of semi-autonomous organizations that collaborate within the context of a federated structure. The goal of RT-25 is to devise a framework and a series of MPTs for Net-Centric Enterprises to manage the capabilities and requirements of the various organizations involved in the Net-Centric Enterprise, taking into consideration the necessity of these units to collaborate using a similar IT system, possibly requiring integration or merging; the existence of legacy systems; and the evolution of missions and needs over time.

Methodology: The overall method devised by this RT was to decompose the capabilities decided upon by the participating units into the requirements and architectures of the system, while maintaining traceability of these requirements and architectures back to the capabilities they were extrapolated from. A three-step decision making process was created to facilitate this evolution of capabilities:

1. Decision Inputs
   a. Determine decision drivers[1] based on capabilities, requirements, and architectures of system
   b. Existing MPTs (such as Component-Bus-System-Property) exist to refine capabilities
   c. Capabilities, requirements and architectures should be determined by negotiations between participating stakeholders
2. Decision Process
   a. Use decision drivers to determine cost/risk and value of capabilities, requirements and architectures qualitatively and relatively to each other

3. Decision Priorities
   a. Use value and risk/cost to prioritize decisions using prioritization plane

Algorithmic description of using the methodology:

1. Initialization
   a. Articulate top-level capability intents
   b. Identify net-centric actors at all levels
   c. Identify existing systems and architectures
   d. Reconcile capability intents into capabilities
2. Iteration in Decision Framework
   a. Decompose capabilities into functions into requirements
   b. Reconcile capabilities, functions, requirements and architectures
   c. Map capabilities, functions and requirements to architectures
   d. Incorporate evolving needs over time
3. Progress Reporting
   a. Traceability on progress of top-level capabilities
   b. Volatility and conflict assessment
   c. Re-prioritization, re-budgeting, re-scheduling

C.8.2 APPLICATION TO RT-34: RT-25

As this Research Task is mainly concerned with management of multiple large organizations, it is more suited to large systems engineering tasks, rather than small, urgent needs.

Where: The main focus of this research was on the development of requirements between many large stakeholders, and primarily relates to the process aspect of level 2 under requirements. It was specifically focused on being able to construct a set of requirements from a group of capabilities, while maintaining traceability of the requirements back to the capabilities they evolved from.

How: The MPTs defined in this RT were looked at specific to collaborations between multiple large groups working towards one large goal, each having different capabilities and requirements. The research was done looking at IT mergers, though the MTPs should be effective for physical systems. Several different methods were cited to pick one set of capabilities among multiple stakeholders. Ways were then formulated to decompose those into requirements, functions and architectures while at the same time maintaining traceability of those lower functions back to the higher capabilities.

When: Like other MPTs concerned with developing requirements of systems, these must be implemented early in the engineering process in order to be effective. Especially with multiple large stakeholders and a large project, having a defined set of requirements that everyone involved is aware of is important to effective systems engineering. Additionally, these methods were designed for collaborations between large organizations and may not be suited to smaller projects; it might have to wait until all other areas of expedited systems engineering have been scaled up to larger venues.

C.9 SERC RESEARCH TASK – RT27

C.9.1 DESCRIPTION: SYSTEM MATURITY AND ARCHITECTURE ASSESSMENT MPTS

Overview: The three objectives of this research task were to:

1. Identify systems engineering and architectural artifacts to support the assessment of technology, integration and system maturity
2. Correlate systems engineering architectural artifacts to supported views and artifacts in Department of Defense Architecture Framework (DoDAF), that enable Technology and Integration Readiness Level assessment
3. Develop a maturity assessment tool that works with standard industry SE architecture tools

Background: Metrics: measure the attributes of an object of interest, allowing decision makers to make more informed decisions regarding that object. Four rules to successful metrics:

1. The way value is used should be clear
2. The data to be collected for the metric should be easily understood and collected
3. The way of deriving value from the data should be as simple and clean as possible
4. Those for whom the use of the metric implies additional cost should see maximum direct benefit

Descriptive metrics can be objectively measured, are quantifiable, and have minimum variability between observers.

Prescriptive metrics are qualitative, judgmental, subjective, and based on perceptual data.
Strive to make prescriptive metrics of Technology Readiness Level (TRL) and Integration Readiness Level (IRL) more descriptive.

Readiness Levels: TRL has been shown to be an extremely beneficial metric for assessing the risks associated with developing/acquiring a technology; however critics argue that TRL combines many dimensions of technology readiness into one metric. System Readiness Level (SRL) was developed to be a robust, repeatable, agile assessment that could easily be transferred to different applications and architectures. SRL was designed to incorporate both TRL and IRL, and defines a series of levels that articulate maturation milestones for integration activities.

System Architecture and DoDAF: System architecture is an arrangement of elements and subsystems, and the allocation of functions to them to meet system requirements.
Architectures help system engineers examine a system from multiple perspectives, and help decision makers to reason about a problem.

Results: In order to satisfy objectives (1) and (2), the readiness levels were mapped to DoDAF. The first step was to use the TRL Calculator and IRL decision criteria to define the decision criteria for both. The next step was to decide which DoDAF Conceptual Data Models could best address each readiness level decision criteria. The finals steps were to select models from a subset list of all DoDAF models.

In order to satisfy objective (3), an SRL calculator was developed that extracted information from the TRL and IRL in order to report a value for the SRL. It was also designed to be useable with multiple systems architecting tools with minimal modifications.

C.9.2 APPLICATION TO RT-34: RT-27

Where: The MPTs developed in this research are most applicable to the use of mature technology under the product aspect of level 1. This research combined two pre-existing MPTs to measure the readiness of software systems and combined them, creating a method of determining the overall readiness of a software system quantitatively.

When: SRL levels of existing systems and technologies should be looked at during the requirements and concepts engineering phases of an SE project. This way, it can be determined if a system is adequate for integration before the design process starts, or it can be deemed unusable and a different system can be chosen for analysis, rather than discovering half way through the design process that a system is not fit for integration and having to start over from scratch.

How: Using the SRL quantifies how well technologies and systems can be integrated together. This negates the need for guesswork or qualitative analysis in favor of more reliable, unbiased data. Using this, several technologies can be compared to determine which is a better fit, or one existing technology can be looked at to see if it is worth the potential risk to the total system to attempt to integrate it, or if it would be more beneficial to spend the time to develop a better fitting technology to lower the risk.

C.10 SERC RESEARCH TASK – RT 30/31

C.10.1 DESCRIPTION: GRAPHICAL CONOPS

Overview: Create a 3D, virtual environment where stakeholders and concept engineers can collaborate to create and test design concepts in real time. Scenarios can be run with these models, receiving instant feedback and data so that modifications can be made and then re-tested.

Need: Textual CONOPS can take months to make and may not involve the customer. They aren't interactive and are incapable of running "what if" scenarios. Graphical CONOPS allow multiple stakeholders to collaborate with concept engineers, which may allow better communication of needs and requirements as well as better insights into the operating systems.

3D gaming has been shown to increase productivity by channeling intuition. It makes us happier and more creative. When faced with the task of modeling a protein-cutting enzyme, 3D gamers were able to come up with a structure in three weeks, whereas scientists had been struggling with a solution for over a decade. Similar productivity and efficiency may be possible with Graphical CONOPS.

Concept: The creation of the Graphical CONOP would be collaborative between two people or groups of people:

Primitive Developer

- Highly technical
- Programming skills
- Technical assistance during primitive development

CONOPS Author

- Not expected to have programming experience
- Knowledge of domains and subject matter

Primitives are 3D models with one or more domains or attributes. Can be immature with a 3D model, or a domain or both but no specified attributes, or mature with all attributes specified, potentially with extra attributes.

CONOPS Author is responsible for choosing and linking primitives to create a system. The Primitive Developer imports objects, creates primitives and assigns attributes to the primitives.

C.10.2 APPLICATION TO RT-34: RT-30/31

Where: Graphical CONOPS are most applicable for requirements development, under the process aspect of level 2. Due to the collaborative nature amongst the stakeholders and engineers, it could also be conducive to the intense knowledge sharing aspect of level 2. Also, due to the digital platform that the CONOPS are developed on, it can relate to the digital enablement mentioned that facilitate level 2.

How: Stakeholders work with programmers to develop models of a system they believe will meet their needs and requirements. Programmers are then able to execute different scenarios using these models with real time results and feedback that can be analyzed to update the model, after which more scenarios and tests can be run. This way, stakeholders can be sure that their needs are being met, and engineers can have real data with which to make necessary changes to improve their initial designs faster, shortening the development time significantly.

When: CONOPS in general are developed in the beginning of a project, and the Graphical version is no different. This is the initial stage of development where the stakeholder requirements are synthesized into a system to be created.

C.11 SERC RESEARCH TASK – RT-35

C.11.1 DESCRIPTION: KANBAN IN SYSTEMS ENGINEERING

Overview: A Kanban (signal card) is a method of on-demand scheduling that provides a visual means to manage flow within a process. Rather than tasks being "pushed" by a deadline, tasks are "pulled" based on availability of resources (signal cards) to complete that task. Each signal card is created with an agreed capacity for work, and one card is associated with each piece of work. Work is assigned to cards based on determined value and once all cards are in use, no further work is assigned until more cards are freed up. The purpose of this research is to determine the applicability of Kanban scheduling to systems and software engineering in a rapid response environment.

Goals: The overall goal of this research is to verify if using Kanbans to organize projects results in better project performance. Project performance is measured through a value function and is seen as achieving value along one or more of the three following scales:

- Shortest-time to useful-value
- Highest-value for a given-time
- Lowest variation in transit time

Value: Using an on-demand Kanban method of scheduling was predicted to provide value in five different ways:

1. More effective integration and use of scarce systems engineering resources
   a. Value functions can be tailored to provide efficient scheduling, maximizing value provided by resources
   b. Can help determine if delaying other service requests is warranted based on what is currently being executed

2. Flexibility and Predictability
    a. Operates with shorter planning horizons, increasing flexibility
    b. Provides predictability despite dynamic planning
3. Visibility and coordination across multiple projects
    a. Synchronize activities across mutually dependent teams by coordinating their activities through changing value functions
    b. Show status of work-in-progress and queued/blocked work
    c. Decreases impact of long latency dependency between work items by not starting work on items that require other items to be complete
4. Low governance overhead
    a. Doesn't require major changes in way work is accomplished or imply specific organizational structures
    b. Can be implemented for individual projects and evolve into more effective governance as better ways to obtain value are discovered
    c. Visual representation of flow makes issues easily identifiable
    d. Metrics are inherent to the system, clearly identify problems, and help track improvements
5. Increased project and system value delivered earlier
    a. Limits work in progress to integrate systems and project engineering
    b. Provides specific project and system-wide work item value determination
    c. Maintains long-term investment

C.11.2 APPLICATION TO RT-34: RT-35

Where: The Kanban scheduling system relates to both the real-time management aspect of level 3, and the intense knowledge sharing aspect of level 2. Kanban also enables scheduling flexibility, by allowing changes to be made to how work is done if the requirements change, or if tasks end up being more work intensive than originally expected. The continuous integration also allows for complete project visibility amongst the entire team, and ensures that all the separate parts work together as they are supposed to.

When: As it is a scheduling method, Kanban is best implemented after the requirements and concept development part of a design project are complete so that the work involved to complete a project is known. One of the key aspects of Kanban, however, is that tasks and resources may be modified throughout the lifecycle of the project to fit changing or emerging requirements, or adapt to unforeseen circumstances.

How: One of the points made in this research was that it didn't require much change to the way a team accomplishes work in order to implement a Kanban scheduling system. It is recommended that an organization use this system for individual projects at first, and allow it to evolve into a more effective governance as they become more comfortable with it, and as they begin to understand better ways to obtain value from it.

APPENDIX D. RECOMMENDATIONS FOR DIGITALLY-ENABLED RAPID ACQUISITION

There are practices that the commercial world is increasingly reliant on, but were not necessarily seen in the government rapid organizations we visited. We may not have seen these digitally-enabled, information technology centric rapid practices because we didn't explicitly ask questions about them or because the use of some technology and tools is limited due to government security concerns, restrictions or classification. Below, we present some examples of digital enablement that we have observed in commercial firms that we suggest have the potential to facilitate the characteristics described in Group 3, such as more intensive knowledge sharing and rapid decision making in DoD acquisition.

OBSERVATION D.1: IN COMMERCIAL ENTERPRISES, A PRIORITY IS GIVEN TO SHARING QUICKLY CONSUMABLE CROSS-DATA-SOURCE INFORMATION

In the commercial world, data are increasingly shared automatically to keep up with the need for rapid decision-making. Additionally, because rapid decision-making often requires the simultaneous consideration of different people, process, and product elements of the project, often information that is drawn from a variety of different data sources need to be shared. However, all this sharing often quickly leads to information overload. Thus, commercial rapid projects identify ways to make information from multiple data sources not only available but quickly consumable.

One way in which vast amounts of information is shared in a consumable way is through the use of key performance indicators (KPIs) and thresholds that, when exceeded, trigger a message sent to others. For example, at Western Digital, KPIs and thresholds for in-process manufacturing scrap are used to signal to operations, engineering, and sourcing personnel when, in any hour, scrap rates are higher than the expected threshold (Houghton et al 2004). For non-transactional data, such as customer conversations on internet discussion boards, KPIs and semantic analysis tools are used as well to help identify customer trends and then to automatically alert marketing personnel of the opportunity for new products or services (Arthur 2012). KPIs can be used with keyword searches of customers' use of social media, for example, to alert communications personnel of the need for rumor or customer damage control (Golla 2012). The application of KPIs to earlier phases, such as concept development are also feasible. KPIs can be established, for example, for traceability, requirements definition, and risk-taking.

Consummability of large quantities of information can be enhanced in ways other than the use of KPIs. One method is to devise and enforce standards around the use, format, and access of many different data sources so that data from the different sources can be combined to lead to a more comprehensive picture of a topic (Majchrzak and Maloney 2008, Mulholland 2006). At a health care organization, for example, data from a patient's past Xrays, blood tests, prescriptions, and office visits have been electronically standardized so that emergency room doctors can receive the information they need immediately upon the identification of an emergency room patient, resulting in the saving of lives. Or, when an engineer needs to know how to make immediate improvements in a proposed manufacturing process, the ability to access and combine data from the vendor, past manufacturing output of similar products, and past maintenance records can help the engineer to quickly answer the question. While our interviews indicated some attempt to create spreadsheets that allowed for different engineers to quickly do trades analyses (e.g., Aerospace's CDC), and some use of KPIs underlying project management dashboards, we found little effort to create standardized databases to support cross-source consummability.

OBSERVATION D.2: IN COMMERCIAL ENTERPRISES, SOCIAL NETWORKS ARE USED, IN REAL-TIME, TO FIND AND SHARE INFORMATION.

In commercial firms, social media tools are increasingly used to alert others within a firm of the need for help in problem-solving or service provision. Sales personnel use instant message tools such as Chatter to inform others of customer needs (Vance 2011). Twitter is used internally to a firm to solicit problem-solving help by brief messages of the need for information or problem-solving help are broadcast to employees, typically resulting in immediate response (Duffy 2011).

Individuals in commercial firms are also increasingly using firm-based social media to be instantly alerted about new knowledge. At IBM, for example, employees use their internal Facebook-like profiles to indicate the projects they are working on, including the posting of recent reports or listing of books they find interesting to their work (Majchrzak et al 2009). Other employees "follow" these employees so that they are informed about the new documents as well. At Novell, a wiki about competitors exist (Wagner & Majchrzak 2006,2007) to which many employees subscribe. As employees attend conferences, participate in online forums, or become aware of competitors' actions in other ways, the employees post their observations to the wiki, instantly updating the hundreds of other employees who have subscribed to the wiki.

While, our interviews yielded a small amount of use of instant messaging for rapid communication, we found no use of social networks for informing rapid personnel.

OBSERVATION D.3: USE OF "LIVING TEAM TOOM" TECHNOLOGIES AND PROCESSES ENABLE SUCCESSFUL PROGRAMS

There has been significant research on the new forms of working that virtual teaming demands (e.g., Majchrzak and Malhotra 2003, Majchrzak et al 2004, Malhotra and Majchrzak 2004, 2005, Malhotra et al 2001, 2007).   A living team room concept is one that replaces email by people altering their work processes so they communicate by posting draft ideas into a single workspace, that also has version control, searching and chat capabilities, templates for meeting minutes, ability to comment on others' draft ideas, and a repository to house finished documents are integrated into a single workspace and a redesigned work process. Their redesigned work process leverages the unique advantages provided by asynchronous and synchronous conversations: with synchronous, team members have the opportunity to engage in rapid back and forth dialogue to come to a common understanding of a problem or resolution; with asynchronous, team members have the opportunity to think more deeply about a problem and offer creative solutions.

The redesigned work process also leverages the opportunity provided by having "living" documents in a central workspace (such as wikis or modifiable drawings). As such, team members can see what others' are drafting and offer early advice before the idea becomes so well-developed that reluctance to make changes arises. Moreover, by commenting and rewriting each others' work, team members are able to more effectively co-create as they see each other's changes. Having the evolution of the team's common work documented in real-time helps keep members up-to-speed with each other's work and the group's current status, even as people temporarily leave the team for vacations, tours of duty, working on others projects, etc.(Majchrzak and More 2012). Finally, living team rooms have the advantage of providing information about the status of the team to experts or consultants, allowing them to get up to speed rapidly.

While we did observe some use of Sharepoint in this rapid organizations and one that was experiments with a chat room, the uses were restricted to information repositories, rather than that of a living workspace.

OBSERVATION D.4: INTERNAL CROWDSOURCING CAN RAPIDLY GET CREATIVE ANSWERS TO COMPLEX PROBLEMS.

DARPA Crowd Sourcing Demonstration
• 2004 DARPA Balloon experiment! • 10 Weather Balloons released across US • First group to find all balloons wins $40,000 cash prize • MIT found balloons in 9 hours • Social Networking Technologies • Sliding scale with monetary incentives to find balloons • Monetary rewards for inviting person to find balloons

Simply because a project team is working on a project doesn't mean that they have the complete knowledge needed to generate the most creative solutions around difficult complex problems. To be rapid, companies are increasingly moving toward internal crowdsourcing, in which they announce "challenges", and then ask people to contribute their ideas (Chesbrough 2006). Recently, these challenges are becoming more collaborative, so that ideas are not just being contributed, but are co-created into more complete solutions. Challenges can be announced for very short timeframes, and people external to the team can become invested in helping to resolve the problems. In the past, posting challenge problems was interpreted as a negative reflection on the team's inability to solve its own problems. More recently, posting challenge problems are being perceived as a way to more rapidly resolve problems with fewer internal resources, a more positive and rapid way to solve problems [Chesbrough 2006].

OBSERVATION D.5: INTEGRATIVE TOOLS CAN BE USED FOR ALL THREE ELEMENTS OF RAPID (PEOPLE, PROCESS, PRODUCT) IN THE AREAS OF: ESTIMATION OF COST AND SCHEDULE, ORGANIZATIONAL FIT.

To accelerate the system development, the program should be able to estimate or assess their status and find out where they stand. Two tools that have been selected to highlight in relation to RT-34 are TOP Modeler and Constructive Rapid Acquisition Development Model (CORADMO). For each tool, a description is provided as well as a context for when, why, and how the tool could be applied to expedited development. TOP Modeler is described herein. An introduction to CORADMO is in this appendix, and a separate paper with more details is in Appendix E.

TOP MODELER

The Technology Organization and People (TOP) Modeler, as the name suggests can support organizational design and analysis. Using a knowledge-base from years of collected data and research literature, TOP Modeler can help to optimize (and expedite) an organization's system development processes. This can help examine the strong relations to the observations in Group 1 and identify an integrated approach to people (organization), process and product (technology). For more information,
http://www-bcf.usc.edu/~majchrza/topmodeler/about-topmodeler.html

What: TOP modeler is a tool developed to support *organization* analysis, design, and reengineering with respect to emergent knowledge processes. TOP stands for "Technology, Organization, and People" integration. Structurally, the TOP Modeler system has three main components: a knowledge-base of the scientific knowledge about organization design, an inference engine, and an interface for data input and analysis display.

Why: To expedite the system development process, the TOP Modeler can help to optimize organizational capabilities with respect to knowledge development, capture, management and application. The stakeholders can use TOP Modeler to analyze, design, reengineer, or improve program /project/organization status.

When: Anytime in the project lifecycle, especially at the beginning, the program manager or responsible person can use TOP Modeler to evaluate their current program/organization status or evaluate their alternative to-be future skills, processes, and tools.

How: The gap for improvement can be assessed when the stakeholder/user describes their operation/business strategies. These current strategies are compared with best practices and the TOP Modeler informs the users of prioritized gaps that need to be mitigated. The gaps are described in terms of a) 3 types of operation/ business strategies, which are Business Objectives, Process Variance Control Strategies, and Organizational Values, and b) 11 enterprise features, which are Information Resources, Production Process Characteristics, Empowerment Characteristics, Employee Values, Customer Involvement Strategies, Skills, Reporting Structure Characteristics, Norms, Activities, General Technology Characteristics, and Performance Measures and Rewards. As shown in figure D-1, the TOP Modeler Ferris Wheel shows the color-coded thermometers of each operation/business strategies and enterprise features, which indicate the percentage of features of current organization status matched to benchmarked best practices designate by the user.
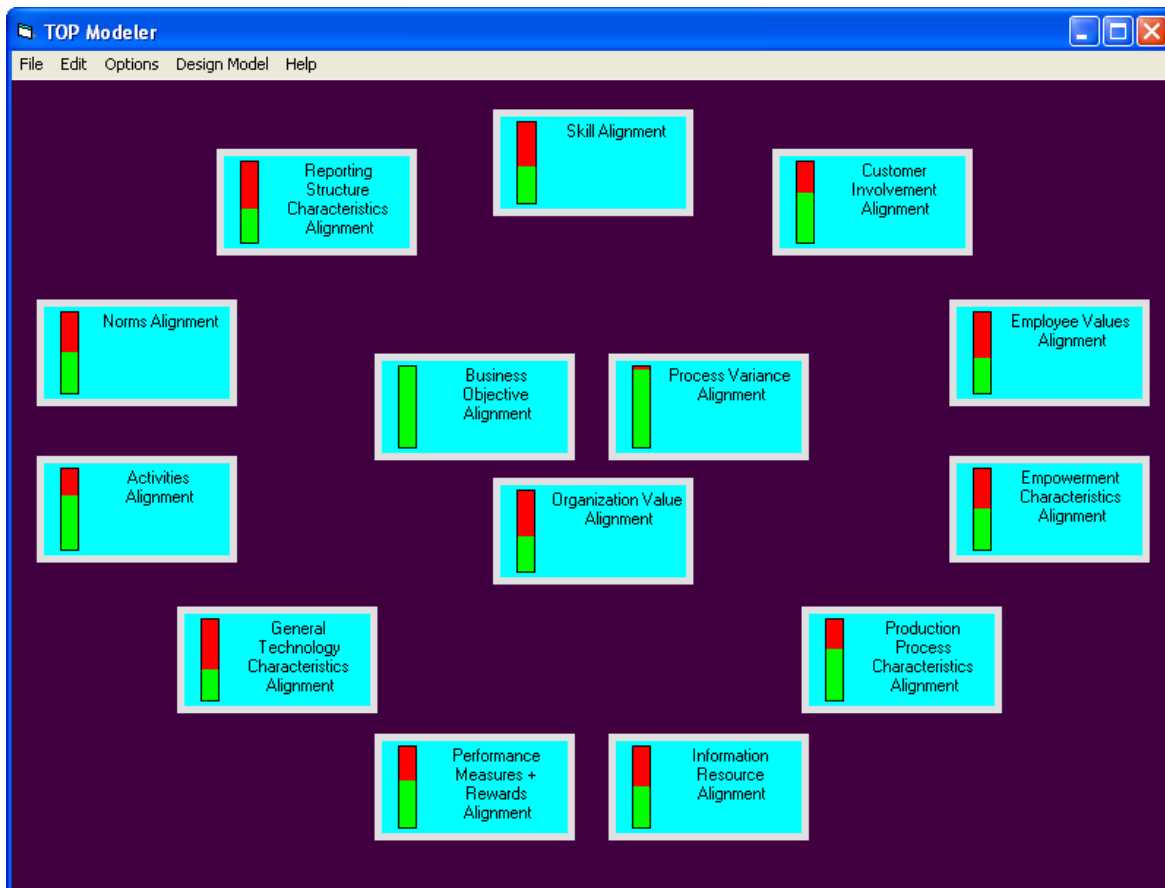
Figure D-1: The TOP Modeler Ferris Wheel

To provide a quick performance status update, tradeoff matrices provide immediate feedback to stakeholders on their standpoint (Figure D-2). If the current organization's operation/business status aligns with the expected organization's operation/business strategy, the cell will be shown in green; otherwise it will be in red. This feedback will quickly report the weak aspects and encourages users to improve their process in order to achieve a better project performance.

Figure D-2: The TOP Modeler - Example Tradeoff Matrix

Where: The TOP Modeler has been used in over 50 applications of organizational redesign, business process redesign, or implementation of new manufacturing technology. US Air Force, ManTech program, the National Center for Manufacturing Sciences, Digital Equipment Corporation, Texas Instruments, Hewlett Packard, Hughes, General Motors, and the University of Southern California.

Foundation: Through extensive literature search and standard setting process facilitated by National Center for Manufacturing Sciences (NCMS), the inference engine, the knowledgebase and the rules were derived from sociotechnical systems theory and various literature reviews. TOP Modeler's knowledgebase was developed with the support from the U.S. Air Force ManTech program, the National Center for Manufacturing Sciences, Digital Equipment Corporation, Texas Instruments, Hewlett Packard, Hughes, General Motors, and the University of Southern California. Information about the development of TOP Modeler can be found in Markus et al (2002).

We researched this tool as a potential candidate for assessing inter-dependencies of critical success factors. However, the tool required significant "modernization" to apply to today's software environment (such as the latest version of Windows). The concept remains valid if future research requires this analysis.

CORADMO

What: CORADMO is part of the Constructive Cost Model (COCOMO) suite of software and systems engineering tools to estimate development cost, illustrated in Figure D-3. CORADMO stands for Constructive Rapid Application Development Mode, with RAD referring to application of any of a number of techniques or strategies to reduce software development cycle time. COCOMO has been used over 30 years by software developers worldwide. CORADMO extension has been recently updated to better reflex more recent agile and expedited processes.

The foundation of CORADO is the COCOMOII tool which uses 5 scale drivers and 17 cost factors that characterize the team, processes, tools, and software product characteristics to calculate estimated effort and schedule for the software development activities. Again note the strong relations to Level 1 observations which integrate people, process and product. CORADMO provides the assessment of potential schedule savings due expedited processes.

CORADMO has 5 multiplicative cost factors (product, process, project, team, and risk acceptance) as illustrated in Table D-3. Under each multiplicative cost factor, there are sub factors that identify various ways to expedite system and software development.
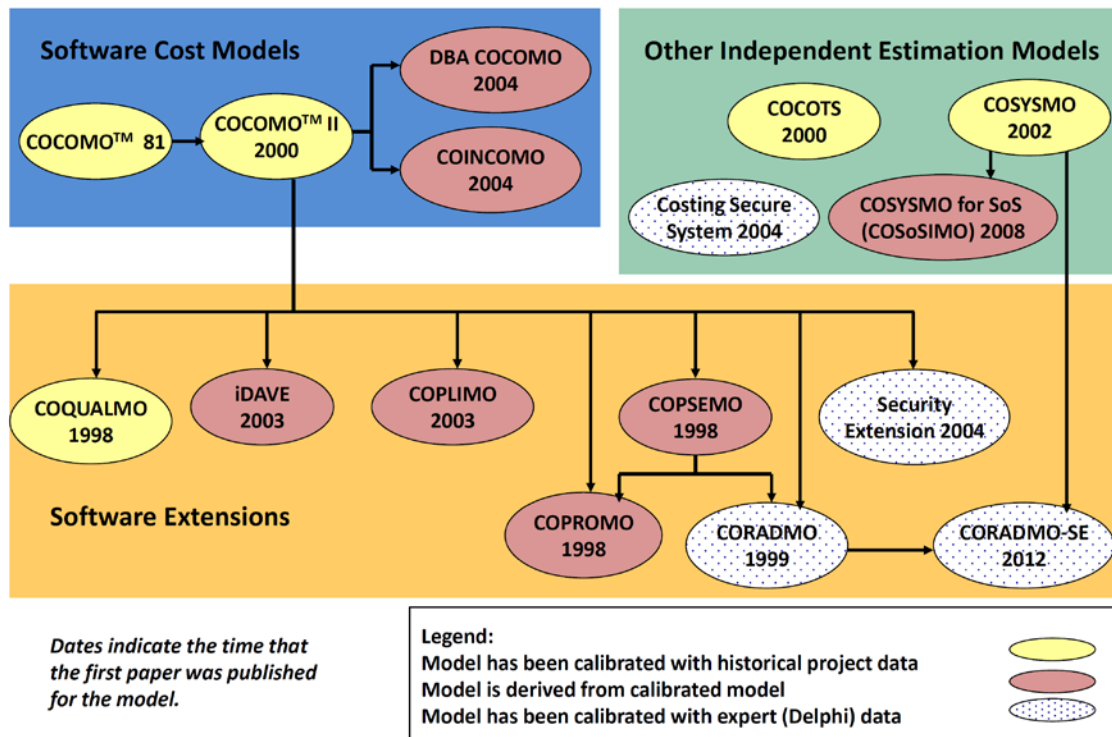
Figure D-3: COCOMO Suite of Engineering Estimation Model

Why: To understand the range of potential of schedule savings due expedited processes.

When: When the organization wants to evaluate alternative processes for system and/or software development. The earlier to use and guide the process, the more saving can be realized.

How: The CORADMO tool uses user ratings of the CORADMO parameters described in Table D-1 to calculate the estimated schedule savings. More information can be found in the following case studies.

Where: has been used by many DoD contractors since 2005. CORADMO extension has been recently updated to better reflex more recent agile and expedited processes.

Foundation: CORADMO is an extension to the systems engineering model (COSYSMO) that estimates the schedule saving associated with expedited & agile processes. COSYSMO uses 14 cost parameters to characterize the team, processes, tools, and system product characteristics to calculate estimated effort. Recently, the schedule algorithm has been developed to calculate the estimated schedule based on estimated effort and to provide the needed inputs to the CORADMO system engineering calculation. COCOMOII, COSYSMO, and COSYSMO schedule algorithm are primarily based on US DOD system and software development programs.

Appendix E gives a perspective of a specific example.

To better understand the MMPTs (Models, Methods, Processes, Tools) project factors, Table D-1 shows examples of how MMPT's differ between typical, traditional and Expedited/Lean/Agile projects.

Table D-1: Methods, Processes, Tools for Traditional and Expedited System / Software development

Category	Traditional Development	Expedited / Lean / Agile Development
Project Tracking	• Earned Value Management System • Formal meetings	• Burndown / Velocity charts • Stand-up meetings • Kanban
Project Planning	• Formal Plans • PERT/Gantt Charts	• User Stories • Kanban/ Scrum • Planning Poker
Configuration Management	• Formal Change Control • Source Code Control	• Feature Tracking • Shared Repository • Wiki
Requirements Management	• Formal Change Control Board • Contract Changes	• Winbook (Requirements negotiation, management, refinement)
Quality Assurance	• Formal reviews • Formal action items tracking • Test plans/ procedures/ scripts • Simulation • Built-in Test	• Peer reviews / pair programming • Markups / informal notes / immediate changes notification • Test-Driven Development • Automated Testing Tools • Problem Tracking
Design	• Top Down Development • Reuse/COTS	• Combination of innovation, reuse/COTS, prototyping, refactoring
Modeling	• Formal models (e.g. SysML, DODAF CAD/CAM) with change control	• 3D printing • Informal models, sketches for extension to platforms during innovation / prototyping
Risk assessment & Improvement	• Quantitative risk assessment and mitigation	• Risk Exposure Chart

OBSERVATION D.6: MANY OTHER SYSTEMS ENGINEERING METHODS, PROCESSES AND TOOLS (MPT) ARE BEING RESEARCHED THAT WILL SOON MATURE FOR USE.

It became clear during the early execution of this Research Task, that many of the other SERC RTs may generally improve Systems Engineering within any program, with a side effect that programs may be more effective, efficient, and ideally quicker. Appendix C reviews several SERC RTs and describes the relationship with RT-34 observations and findings.

This is a draft conference paper that includes RT-34 collaborators from USC. It has been submitted to the "International Conference on Software and Systems Process" (ICSSP) 2013, to be held May 18-19, 2013, in San Francisco, CA. It further explores the use of CORADMO as a tool for estimating agile project schedule acceleration.

A Model for Estimating Agile Project Schedule Acceleration

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Abstract— **Accelerating development schedules is increasingly important in a competitive world. Reduced time-to-market is a key response to competitive threats in the commercial sphere, and rapid response in deploying military systems may save lives in a geopolitical environment characterized by rapidly emerging and ever-changing physical threats. Agile/lean development methodologies show promise in providing the desired schedule acceleration, but it can be difficult for planners to determine the effects of these factors on schedule duration, and to make appropriate choices to optimize project performance. The Constructive Rapid Application Development Model (CORADMO) attempts to quantify the effects of key schedule drivers, and thus enable planners to estimate the relative schedule that will result from varying these parameters.**

Index Terms— **Agile, CORADMO, estimation, lean, modeling, rapid development.**

INTRODUCTION

Accelerating development schedules is increasingly important in a competitive world. Reduced time-to-market is a key response to competitive threats in the commercial sphere, and rapid response in deploying military systems may save lives and deter adversaries in a geopolitical environment characterized by rapidly emerging and ever-changing physical threats. Agile/lean development methodologies show promise in providing the desired schedule acceleration, within certain problem domains and organizational characteristics [1].

However, we have found that many projects experience slower schedules by jumping into agile methods without awareness of their pitfalls. These include making easiest-first, hard-to-refactor architectural commitments, choosing unscalable or incompatible off-the shelf products, accepting unsuitable on-site customer representatives, teambuilding insufficiently, or assuming low personnel turnover.

The Constructive Rapid Application Development Model (CORADMO) attempts to quantify both the positive and the negative effects of key schedule drivers, and thus enable planners to estimate the relative schedule that will result from varying these parameters. CORADMO is a derivative of the revised Constructive Cost Model (COCOMO II) [2], which was calibrated against larger projects that were typically optimized to reduce cost. In contrast, the goal of projects using agile/lean techniques is often to compress schedule. Further, COCOMO II generates unreasonably high duration estimates for projects of fewer than two person-years of effort, and does not explicitly consider rapid development techniques.

The original CORADMO described in Chapter 5 of [2] operated as a post-processor to adjust the cost and schedule estimates coming from the standard cost-optimized COCOMO II estimates. The COCOMO II schedule model estimates the project duration D in calendar months as 3.67 times roughly the cube root of the estimated effort in person months (PM). Thus, a 27 PM effort would result in an estimated duration of 3.67 * 3 = 11 calendar months, and an average staffing level

of 27/11 = 2.45 people. Such a small team minimizes communications overhead and optimizes effort, but 11 months is excessively long for a competitive or a much-needed product.

As we were calibrating COCOMO II, we were also seeing time-competitive early-agile projects completing 27-PM projects in 5 months by putting an average of 5.4 people on the project. In some well-jelled, domain-experienced Rapid Application Development (RAD) organizations, they could often put 9 people on a 27-PM project and finish in 3 months.

This motivated the development of CORADMO. Its COCOMO II post-processor used a nominal square-root relationship between PM and D, completing a 27-PM project in 5.2 months with an average team size of 5.2 people. It then adjusted the nominal schedule and the originally-estimated effort by applying some schedule acceleration-deceleration factors such as component reuse, asset prepositioning, process streamlining, collaboration technology, early architecture and risk resolution, and RAD personnel-team capability.

The effort and schedule multipliers for these factors

TABLE I. SCHEDULE ACCELERATORS AND RATING FACTORS

Accelerators/Ratings	Very Low	Low	Nominal	High	Very High	Extra High
Product Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity	Extremely complex	Highly complex	Mod. complex	Moderately simple	Highly simple	Extremely simple
Element Reuse	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Low-Priority Deferrals	Never	Rarely	Sometimes	Often	Usually	Anytime
Models vs Documents	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Key Technology Maturity	>0 TRL 1,2 or >1 TRL 3	1 TRL 3 or > 1 TRL 4	1 TRL 4 or > 2 TRL 5	1-2 TRL 5 or >2 TRL 6	1-2 TRL 6	All > TRL 7
Process Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	Highly sequential	Mostly sequential	2 artifacts mostly concurrent	3 artifacts mostly concurrent	All artifacts mostly concurrent	Fully concurrent
Process Streamlining	Heavily bureaucratic	Largely bureaucratic	Conservative bureaucratic	Moderate streamline	Mostly streamlined	Fully streamlined
General SE tool support CIM (Coverage, Integration, Maturity)	Simple tools, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Project Factors	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)	Over 300	Over 100	Over 30	Over 10	Over 3	≤ 3
Collaboration support	Globally distributed weak comm. , data sharing	Nationally distributed, some sharing	Regionally distributed, moderate sharing	Metro-area distributed, good sharing	Simple campus, strong sharing	Largely collocated, Very strong sharing
Single-domain MMPTs (Models, Methods, Processes, Tools)	Simple MMPTs, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Multi-domain MMPTs	Simple; weak integration	Minimal CIM	Some CIM or not needed	Moderate CIM	Considerable CIM	Extensive CIM
People Factors	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)	Weak KSAs	Some KSAs	Moderate KSAs	Good KSAs	Strong KSAs	Very strong KSAs
Single-Domain KSAs	Weak	Some	Moderate	Good	Strong	Very strong
Multi-Domain KSAs	Weak	Some	Moderate or not needed	Good	Strong	Very strong
Team Compatibility	Very difficult interactions	Some difficult interactions	Basically cooperative interactions	Largely cooperative	Highly cooperative	Seamless interactions
Risk Acceptance Factor	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
	Highly risk-averse	Partly risk-averse	Balanced risk aversion, acceptance	Moderately risk-accepting	Considerably risk-accepting	Strongly risk-accepting

were determined such that a well-jelled, domain-experienced RAD project would be estimated as 9 people on a 27-PM project for 3 months, but that a misguided RAD project would take more like 40 PM and 9 months. Unfortunately, in the pre-2000 time frame, we did not have a critical mass of data to calibrate such a model. Recently, though, we have been participating in some research on expediting systems and software engineering via lean and agile methods, that led to a expanded set of product, process, project, people, and risk factors that account for relative schedule acceleration and deceleration [3]. These looked like a better basis for developing a revised CORADMO set of schedule drivers and rating scales, and are discussed next.

METHOD

The Systems Engineering Research Center (SERC) Research Task RT-34, "Expedited Systems Engineering for Rapid Capability and Urgent Needs," was tasked to study ways that systems engineering might be expedited, particularly within the aerospace/defense community. Through industry and government contacts, the study identified candidate firms and agencies that had a history of successfully compressing the development time of projects. In a series of onsite visits and in-depth follow-up interviews, the study identified a set of key factors [4] that, in combination with factors derived in the earlier CORADMO research [2], could be used to model RAD projects' schedule acceleration (Table I). These factors fall in the categories of product, process, project, people, and risk.

Product factors describe the nature of the system to be developed across five sub-factors: simplicity, ability to reuse existing elements, ability to defer lower-priority requirements, degree that models (prototypes, simulations, etc.) can be substituted for written documentation, and maturity of the component technologies.

Process factors characterize the development methodology using three sub-factors: concurrency of artifact development (operational concept, requirements, code, etc.); degree of process streamlining; and the coverage, integration, and maturity (CIM) of tools used to support the development process [5].

Project factors span four sub-factors describing execution of the development effort: project staff size;

degree and nature of team collaboration; CIM of the single-domain models, methods, processes, and tools (MMPTs) employed; and CIM of the multi-domain MMPTs used, where required.

People factors describe the project staff using four sub-factors: general knowledge, skills, and a*g*ility (or, ability to thrive with the more chaotic nature of the agile/lean process) [1]; KSAs specific to the primary problem domain; KSAs spanning multiple problem domains, where needed; and team compatibility [6].

Finally, the *Risk* factor characterizes the project stakeholders' willingness to accept rapid but imperfect solutions [1]. Stakeholders may range from highly risk-averse, to strongly risk-accepting.

As discussed in the Introduction, a good baseline estimate for schedule reduction through rapid development methods has been found to be proportional to the square root of effort. CORADMO estimates duration (D) as the product of multipliers associated with the factors described above (F_i) and the square root of baseline effort in person-months (PM), also has multipliers that adjust the original effort estimate to reflect the effect of RAD on effort.

$$D = \prod F_i \sqrt{PM}.$$

As seen in Table I, each of the proposed factors is rated along a 6-value Likert scale ranging from Very Low to Extra High, where factors rating lower in the scale tend to extend the schedule, and those rating higher to reduce it. Initial values of the schedule acceleration multipliers were chosen to span a relatively small range of duration expansion and reduction, pending model calibration. Our evaluation of rapid development projects in this research, however, suggests that people factors [4] and risk tolerance [1]—which tracks willingness to accept some product imperfections to improve schedule—have greater effects than the other factors, which is reflected in the greater span of their associated schedule multipliers.

We evaluated the CORADMO model against a 12-project dataset of diverse but single-company projects executed by a Midwest software development firm that used agile practices, and that supplemented those practices with systems engineering (SE) processes distinguishing their approach from typical BigDesignUpFront-avoiding agile projects. These SE practices included detailed business process analyses,

Delphi estimates of software testing effort, risk-based situation audits, and componentized architectures, among others. Use of systematic SE processes by the firm was considered to make these projects more comparable to the SE practices applied in the more complex aerospace/defense projects from which the factors in Table I were derived.

The model was also applied to a case study derived from observations of aerospace and commercial firms that have been affiliated with the Center for System and Software Engineering (CSSE) at the University of Southern California (USC). While this case study is not directly traceable to any single firm, it is representative of the range of projects and capabilities that we have seen in real firms. This application of the model allowed us to characterize the types of schedule effects that one might expect to see by varying the factors, which we plan to validate against actual projects in future research.

RESULTS

CALIBRATION TO COMMERCIAL RAPID DEVELOPMENT PROJECTS

Table II presents a dataset of twelve commercial rapid development projects ranging in size from 10 KLOC (thousands of source lines of code) to 400 KLOC, of varying complexity and technology. We rated these projects against the Product, Process, Project, People and Risk factors discussed above to compute the

product of the schedule acceleration factors, and to compare them against the *D/√PM* calculated from the reported project duration and effort.

Factor ratings were selected based upon the reported characteristics of each project, and of the firm as a whole. The projects that employed C++ technologies received Low (L) Product Simplicity ratings as compared with the other HTML-Visual Basic projects and the described product complexity; the "Hybrid Web/Client Server" Product was rated Low (L) due to its high degree of innovation and requirements churn. For the Process factor, most projects used a highly concurrent development process, resulting in a Very High (VH) rating; some projects reported using more complex mixes of technology that suggest less concurrency, and therefore received lower ratings. Reported variation in project staff sizes is the primary reason for the varying Project ratings. The staff was described as being very capable and senior-level, and so the People factor rated at Very High (VH) across the board. Similarly, the firm documented a consistent and rigorous development approach, balancing good engineering against development speed, and hence were all rated at Nominal (N) Risk acceptance.

The product of the selected rating factors is shown in the *Multiplier* column of Table II, and should be compared against the value in the *Duration/√PM* column, calculated from actual duration and effort. The close correspondence of these values in the Error

TABLE II. COMMERCIAL PROJECTS RATING FACTORS AND ANALYSIS

Application Type	Technologies	Person Months	Duration (Months)	Duration / √PM	Product	Process	Project	People	Risk	Multi-plier	Error %
Insurance agency system	HTML/VB	34.94	3.82	0.65	VH	VH	XH	VH	N	0.68	5%
Scientific/engineering	C++	18.66	3.72	0.86	L	VH	VH	VH	N	0.80	-7%
Compliance - expert	HTML/VB	17.89	3.36	0.79	VH	VH	XH	VH	N	0.68	-15%
Barter exchange	SQL/VB/ HTML	112.58	9.54	0.90	VH	H	H	VH	N	0.75	-16%
Options exchange site	HTML/SQL	13.94	2.67	0.72	VH	VH	XH	VH	N	0.68	-5%
Commercial HMI	C++	205.27	13.81	0.96	L	N	N	VH	N	0.93	-3%
Options exchange site	HTML	42.41	4.48	0.69	VH	VH	XH	VH	N	0.68	-1%
Time and billing	C++/VB	26.87	4.80	0.93	L	VH	VH	VH	N	0.80	-14%
Hybrid Web/client-server	VB/HTML	70.93	8.62	1.02	L	N	VH	VH	N	0.87	-15%
ASP	HTML/VB/SQL	9.79	1.39	0.44	VH	VH	XH	VH	N	0.68	53%
On-line billing/tracking	VB/HTML	17.20	2.70	0.65	VH	VH	XH	VH	N	0.68	4%
Palm email client	C/HTML	4.53	1.45	0.68	N	VH	VH	VH	N	0.76	12%

column suggests that the acceleration-deceleration factors are appropriate, although additional work remains in that the calculated factors suggest greater schedule acceleration that was actually observed. The "ASP" project is an outlier that we cannot explain from the data reported.

AGILE SE ADOPTION CASE STUDY

This case study illustrates the use of the revised CORADMO model in explaining the differences in schedule acceleration for various project approaches. The baseline situation for the case study is a hypothetical company division specializing in performing early-SE activities for defense applications in a diversified company, generally involving teams of roughly 20 systems engineers (SEs). The division has traditionally applied a sequential waterfall or "Vee" model to define a system's operational concept and requirements, and then developed a system architecture that satisfies those requirements. Defense needs for rapid response projects, however, have led the division to desire a change to a more agile approach.

The baseline "as-is" factor ratings for the division are shown as boxes marked "X" in Table III. The additional sub-factor detail available in this hypothetical division case study, only some of which was inferable in the commercial data, raises a question of how sub-factors that span a range of ratings should be handled. In COCOMO, a particular rating is chosen based on the preponderance of sub-factors that match the situation, possibly modified based on the expert judgment of the modeler. Here we have decided to average the multipliers, reasoning that higher ratings in some sub-factors offset lower factors in others.

The division's four *product* factor ratings are: moderately complex (N); sufficiently diverse to make reuse infeasible (VL); non-subsettable so that low-priority deferrals are infeasible (VL); able to use models vs. documents only 15% of the time (L); and involving only one or two slightly immature (TRL 6) technology elements (VH).

The three *process* factor ratings for the division are: highly sequential SE processes (VL); largely bureaucratic internal and external project and business processes (L); moderate SE tool coverage, integration, and maturity (H).

TABLE III. AS-IS RATING FACTORS

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity					X	
Process Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	X					
Process Streamlining		X				
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)				X		
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility				X		
Risk Acceptance Factor	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
			X			

The division's four *project* factors are: project SE staff size between 10 and 30 people (H); good collaboration support across several metro-area facilities (H); moderate CIM for single-domain MMPTs (H); and minimal CIM for multi-domain MMPTs (L).

The *people* factor ratings are: good general knowledge, skills, and agility (KSAs) (H); good single-domain KSAs (H); good multiple-domain KSAs (H); but some difficult team interactions (L).

The divisions approach to *risk* is evenly balanced between risk-aversion and risk acceptance, leading to a nominal rating (N) and no effect on the schedule.

The selected ratings result in the following factor multiplier values, which calculates an overall acceleration factor of 1.01, suggesting the division's approach will result in a schedule duration close to the nominal case:

- Product: 1.0*1.09*1.09*1.05*0.92= **1.15**
- Process: 1.09*1.05*0,96= **1.10**
- Project: 0.96*0.96*0.96*1.04 = **0.92**

- People: 0.94*0.94*1.06*0.94 = **0.88**
- Risk: **1.0**

The division initially attempts a change to a more agile process approach by producing multiple artifacts (operational concept, requirements, and architecture) concurrently, instead of sequentially, as shown with the green arrow in Table IV. This was expected to reduce the schedule by 13%, from a 1.09 multiplier to 0.96.

However, when the project was performed, the organization was surprised that the actual schedule was about 15% longer rather than shorter. In performing a review of the cause of this, the division found that the project focused only on its agile and concurrency aspects, and neglected to examine the potential side effects of a too-hasty changeover.

With respect to the other CORADMO factors, the project missed several other factors that affect the overall schedule. These include missed opportunities in addressing some of the improvable SE schedule influence factors, but not others, such as the largely bureaucratic internal and external project and business processes, and the Low-rated multi-domain MMPTs and KSAs. Other detrimental effects resulted from pitfalls in transitioning from sequential, heavyweight processes to agile processes, as illustrated by the red arrows in Table IV:

- *Key Technology Maturity.* In producing artifacts concurrently, the project overlooked some interactions between subsystems, and mischaracterized the maturity of technologies through insufficient analysis. This resulted in a change to a Nominal from a Very High rating, causing a slowdown factor of 1.0/0.92=1.09
- *General SE tool support.* Using a mix of agile MMPTs tools and traditional MMPTs made their MMPTs less integrated, increasing the sub-factor rating to High from Very High, for a slowdown factor of 1.0/0.96=1.04.
- *General SE KSAs.* Rapid development approaches required a different mindset from team members, causing a slowdown factor of 1.0/0.94=1.06.
- *Team Compatibility.* A different style of collaboration is often necessary in agile development, requiring frequent face-to-face

discussions rather than serialized document reviews. Team members or management may be uncomfortable with or hostile to such interactions, resulting in an increase of this sub-factor to Nominal from High, for a slowdown of 1.0/0.94=1.06.

TABLE IV. INITIAL TO-BE RATING FACTORS

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	1.09	1.05	1.0	0.96	0.92	0.87
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity			X			
Process Factors	1.09	1.05	1.0	0.96	0.92	0.87
Concurrent Operational Concept, Requirements, Architecture, V&V				X		
Process Streamlining		X				
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	1.08	1.04	1.0	0.96	0.93	0.9
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	1.13	1.06	1.0	0.94	0.89	0.84
General SE KSAs (Knowledge, Skills, Agility)			X			
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility			X			
Risk Acceptance Factor	1.13	1.06	1.0	0.94	0.89	0.84
			X			

Therefore, although one of the process sub-factors improves as a result of the division's improvement initiative, due to unintended effects several other sub-factors become worse. The resulting CORADMO estimate of the net effect is 0.88*1.09*1.04*1.06*1.06=1.13. Thus, the CORADMO factor analysis not only explained their slowdown factor of about 15%, but also it provided them with a roadmap of further agile improvements they could make to begin to experience agile speedups, along with estimates of the impact that these would have on their schedule.

As illustrated here, when an organization is considering an improvement initiative, it can use CORADMO as a tool to identify potential side effects and analyze their impacts. With this information, the organization can then take steps to ensure these side effects are countered with additional aspects of the improvement initiative, and thus improve the likelihood of achieving a goal of schedule reduction.

Reconsidering its improvement initiative given this analysis, Table V shows the company preparing for the future by restoring the sub-factors whose ratings had worsened to their baseline values (the yellow arrows in Table V), through being aware of the potential problems and therefore taking positive steps to avoid them. This would eliminate an overall slowdown factor of 1.09*1.04*1.06*1.06=1.29. They also added further initiatives, illustrated with green arrows in Table V, to:

- Perform concurrent V&V along with concurrent Operational Concept, Requirements, and Architecture activities, raising the rating to Very High from High, for a speedup factor of 0.92/0.96=0.96
- Improve bureaucratic internal and external project and business processes to be at least moderately streamlined, for a speedup factor of 0.96/1.04 = 0.92.

If these goals were achieved, the resulting CORADMO multiplier estimate would be 1.13*0.96*0.92/1.29=0.77, for a speedup of 23% over their original situation. Further, this schedule reduction would be achieved through improving only three process sub-factors, and simply remaining at the pre-initiative levels for all other factors, through being aware of potential detrimental effects and taking steps to ensure they would not occur.

On their next project, they were not able to realize the full 23% speedup, but were able to realize a 15% speedup factor instead of a 15% slowdown factor. Continuing use of the CORADMO-based schedule acceleration framework enabled them to not only achieve their initial 23% speedup target, but to identify additional improvements that accelerated their schedules even further.

TABLE V. FINAL TO-BE RATING FACTORS

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	1.09	1.05	1.0	0.96	0.92	0.87
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity					X	
Process Factors	1.09	1.05	1.0	0.96	0.92	0.87
Concurrent Operational Concept, Requirements, Architecture, V&V					X	
Process Streamlining				X		
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	1.08	1.04	1.0	0.96	0.93	0.9
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	1.13	1.06	1.0	0.94	0.89	0.84
General SE KSAs (Knowledge, Skills, Agility)				X		
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility				X		
Risk Acceptance Factor	1.13	1.06	1.0	0.94	0.89	0.84
			X			

DISCUSSION

The combination of the original CORADMO model and the additional insights on product, process, project, people, and risk factors provided by the SERC RT-34 analyses enabled the revised CORADMO model to explain the variations in schedule acceleration among the projects in Table II. This is encouraging, but it is unknown to what extent the model will accurately describe projects outside this limited set. We are in the process of collecting additional data points over a wider variety of projects. These data should allow us to better calibrate the model and evaluate its wider applicability. At a minimum, though, the model can be used as a good checklist for assessing an organization's status and prospects with respect to schedule acceleration.

Overall, as was observed in [1], an organization's culture is one of the critical factors in its ability to achieve near-term gains from going to agile methods. A good deal of careful re-culturing is needed to take an organization of people who feel comfortable and empowered by having sets of standard policies, practices, and procedures that

define success in the organization, to an organization where people feel comfortable and empowered when there is a minimum of such standard policies, practices, and procedures. Several of the CORADMO factors can help in gauging an organization's progress in making such transitions.

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